

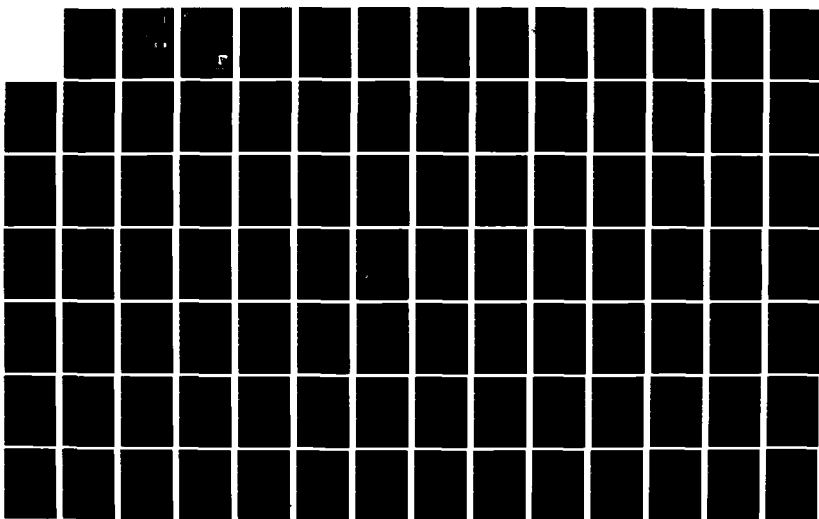
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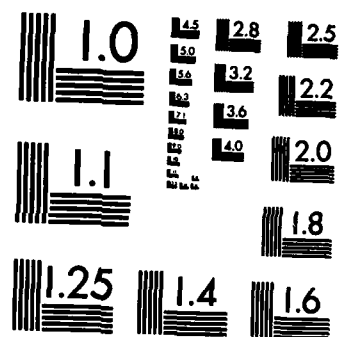
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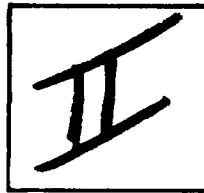


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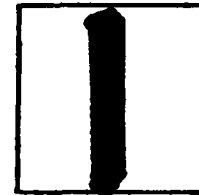
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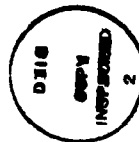
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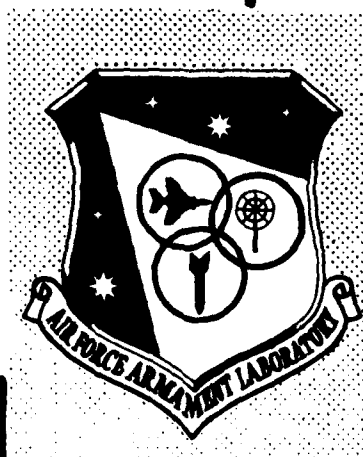
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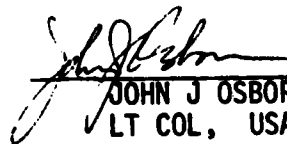
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AFATL TOODY USERS GUIDE

15 FEBRUARY 1977


JOHN J OSBORN
LT COL, USAF

SYMBOLS

c	Sound Speed
n	Cycle Number
s	Slope of the shock velocity/particle velocity curve
DT	Time Step
E	Internal Energy Density
F	Burn Fraction
G	Shear Modulus
K	Bulk Modulus
P	Pressure
PH	Hugoniot Pressure
T	Temperature or Time
U_s	Shock Velocity
U_p	Particle Velocity
Y	Yield strength
α	Distention Ratio
γ	Gruneisen ratio or ratio of specific heats
Γ	Gruneisen ratio
η	Volumetric Strain, $1 - \rho_0/\rho$
$\bar{\eta}$	Compression, ρ/ρ_0
μ	Excess Compression, $\rho/\rho_0 - 1$
ν	Poisson's Ratio
ρ	Density

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SECTION I

INTRODUCTION

[TOODY is a two dimensional (plane or axisymmetric), multi-material, Lagrangian wave propagation computer code. It was written by Sandia Laboratories in the late 1960's.] References 1 and 2 describe one of the early versions. [The Air Force Armament Laboratory's (AFATL) TOODY is that version updated extensively by both Sandia and the Air Force] (primarily Lt Col Osborn while at AFATL and the Air Force Weapons Laboratory).

[The purpose of this report is to document changes made to the code by Sandia and the Air Force and to provide input/output details.] It is expected that the reader will be familiar with References 1 and 2 prior to reading this report.

AFATL TOODY runs on the CDC 6600 computers at Eglin Air Force Base, Florida under the SCOPE 3.4 system. It uses the CDC FTN compiler and the CDC UPDATE system. UPDATE is used to tailor coding to the specific problem being run. It runs most problems at a speed of 1.5×10^{-3} CP seconds per zone per cycle.

The code can be made available by contacting Lt Col Osborn at AFATL/DLJW, Eglin AFB, FL 32542 (AV 872-2141).

A rezoner exists for Sandia's TOODY. It is planned to convert it for use with AFATL TOODY. The conversion has not yet been made. The changes required involve provision for more equations of state and more zone variables.

SECTION II

TOODY MODIFICATIONS

This section provides information on code modification made both by the Air Force and by Sandia Laboratories. The changing office is indicated. The modifications are not discussed in any particular order.

EQUATIONS OF STATE

ELASTIC/PLASTIC (STATE 1)-AIR FORCE

EOS 1 has been slightly modified. An option is now available for Hugoniot pressure as a function of μ (excess compression) = $\rho/\rho_0 - 1$.

$$P_H = \rho_0 c_0^2 (\mu + k_1 \mu^2 + \dots + k_5 \mu^6)$$

Zone variable BT2 is used to store the number of cycles a zone has been in the plastic state. Zone variable BT1 is used to store the number of cycles a zone's pressure has been less than the input value PMIN. These zone variables can be used as flags for indicating plastic and spalled zones on grid plots.

HIGH EXPLOSIVE (STATE 2)-AIR FORCE

An option has been added so that the Jones - Wilkins - Lee (JWL) equation for detonation products can be used. This equation, described fully in Reference 3, is as follows.

$$P = A(1 - \frac{w\bar{\eta}}{R_1})e^{-R_1/\bar{\eta}} + B(1 - \frac{w\bar{\eta}}{R_2})e^{-R_2/\bar{\eta}} + w\rho E$$

where A, B, R_1 , R_2 and w are material constants. At high expansions, $\bar{\eta}$ approaches zero and P approaches $w\rho E$, a gamma-law formulation. Coefficients for several high explosives are given in Table II-1.

TABLE II - 1

JML COEFFICIENTS

HE	ρ_0 (gm/cc)	D (cm/sec)	E (ergs/gm)	A (dynes/cm ²)	B (dynes/cm ²)	R1	R2	W
Comp B	1.717	7.98E5	4.95E10	5.242E12	0.07678E12	4.2	1.1	0.34
CYCLOTOL	1.754	8.25E5	5.25E10	6.034E12	0.09924E12	4.3	1.1	0.35
Detasheet A	1.48	7.2E5	4.73E10	3.738E12	0.03647E12	4.2	1.1	0.3
Detasheet C	1.48	7.0E5	4.19E10	3.49E12	0.04524E12	4.1	1.2	0.3
HMX	1.891	9.11E5	5.55E10	7.783E12	0.07071E12	4.2	1.0	0.3
OCTOL	1.821	8.48E5	5.27E10	7.486E12	0.1338E12	4.5	1.2	0.38
TNT	1.63	6.93E5	3.68E10	3.738E12	0.03747E12	4.15	0.9	0.35

If a zone has not burned, its pressure is computed from

$$P = K_0 \mu$$

or

$$P = \rho_0 c_0^2 \eta / (1 - s\eta)^2$$

In the latter case c_0 and s are set to values appropriate for Composition B -- $c_0 = 2.88E5$ cm/sec and $s = 1.6$. In either event, a message is printed warning of a possible low order detonation if P exceeds 25 kilobars prior to detonation time.

Burn time options have been increased by allowing the user to set a constant value to be added to burn time computed by geometric means. This allows more accurate burning around corners.

IDEAL GAS-SANDIA

EOS 3, the ideal gas equation of state is identical to Sandia's except that energy is now automatically added on cycle 0 to cause the input sound speed to be valid.

COMPRESSIBLE EARTH MEDIA-AIR FORCE

EOS 4 has been written to provide a reasonable formulation for soil and porous rocks. In addition, a built-in concrete model is available.

EOS 4 assumes that pressure is a function of μ and μ_{\max} (the maximum value of μ seen by the zone). The specific form is shown in Figure II-1. An energy variation on pressure is not considered. This should be valid for all but very high energy deposition problems since values for Gruneisen's ratio for earth media and concrete are around 0.1 to 0.3 (as opposed to values from 1.5 to 3 for metals).

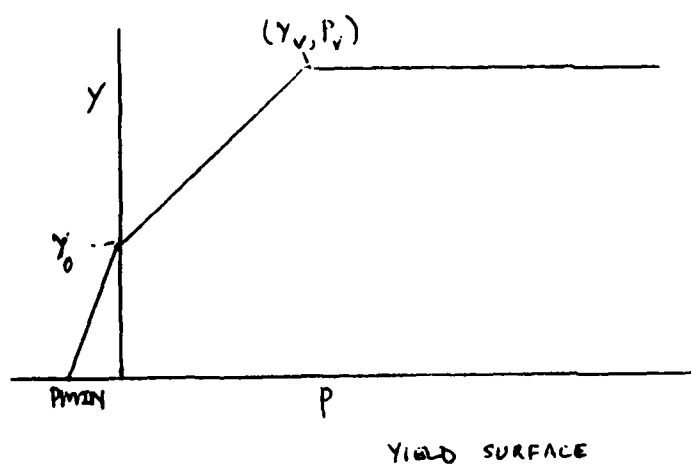
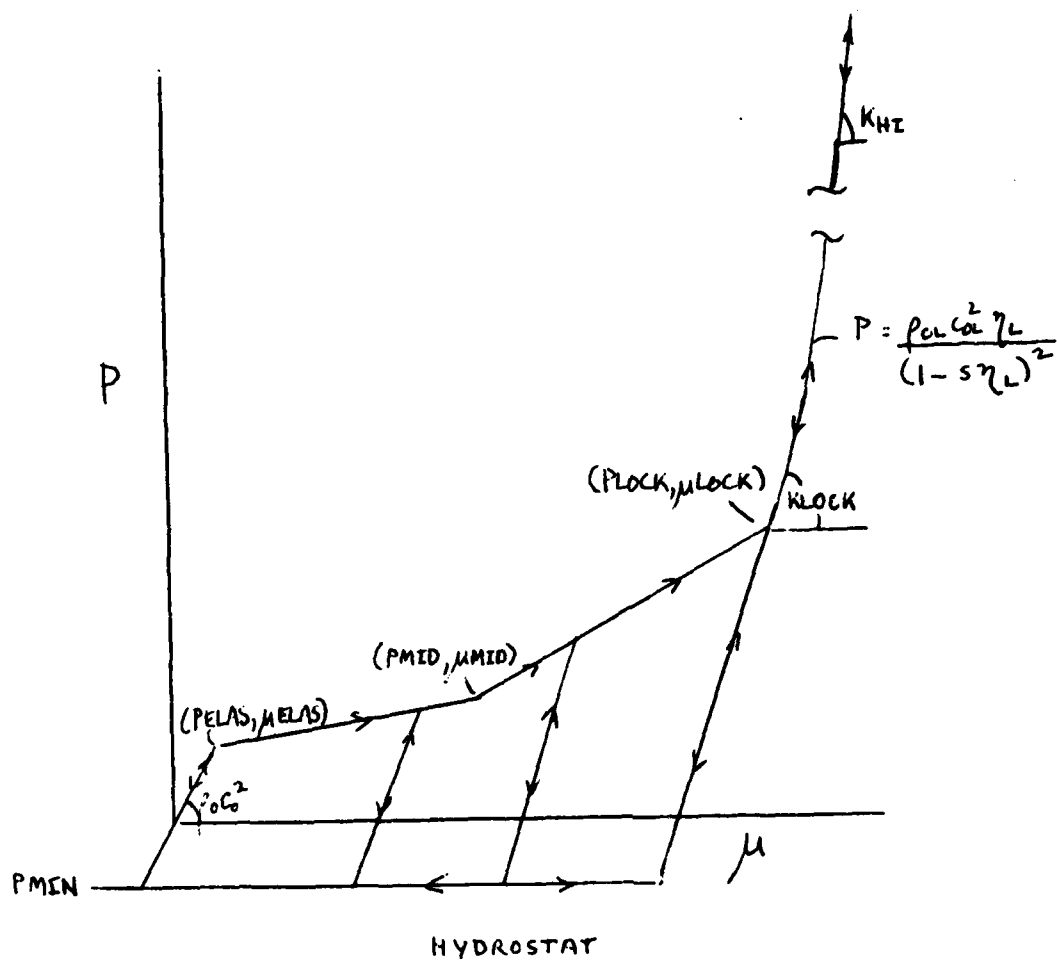


FIGURE II-1

To define pressure the user inputs ρ_0 , c_p , $PMIN$, $PELAS$, $PMID$, μMID , $PLOCK$, $\mu LOCK$, c_{oL} and s . ρ_0 is the initial density of the material. c_p is its seismic P-wave velocity (low pressure longitudinal wave velocity). $PMIN$ is the minimum pressure the material can withstand without breaking up in tension. As seen in Figure II-1, initial loading is along a curve

$$p = \rho_0 c_0^2 \mu$$

Unloading after reaching $PELAS$ but prior to reaching $PLOCK$ is accomplished along a line

$$P = P_{\mu_{max}} - k(\mu_{max} - \mu)$$

where $P_{\mu_{max}}$ is the pressure at $\mu = \mu_{max}$ on the crushup curve and K is a slope which varies from $\rho_0 c_0^2$ when $\mu = \mu_{ELAS}$ to K_{LOCK} when $\mu = \mu_{LOCK}$. Subsequent reloading is also along this line until the crushup curve is reached. When μ_{max} has reached μ_{LOCK} all loading, unloading and reloading is along the lockup curve. The lockup curve is described by three connecting segments

$$\mu < \mu_{LOCK}, P = P_{LOCK} - K_{LOCK}(\mu_{LOCK} - \mu)$$

$$\mu > \mu_{LOCK} \text{ BUT } \mu < \mu_{HI},$$

$$P = \rho_{oL} c_{oL}^2 \eta_L / (1 - s\eta_L)^2$$

where $\eta_L = 1 - \rho_{oL}/\rho$. This is a form suitable for describing the Hugoniot when the shock velocity/particle velocity curve of the Hugoniot can be described by

$$U_s = c_{oL} + sU_p$$

The density ρ_{oL} is computed by TOODY to insure that this lockup curve intersects the crushup curve at $(PLOCK, \mu_{LOCK})$.

If $\mu > \mu_{HI}$, $P = P_{HI} + K_{HI} (\mu - \mu_{HI})$

where μ_{HI} , P_{HI} and K_{HI} are calculated by TOODY simply to prevent running into the pole in the Hugoniot form.

Unloading is limited at all times by P_{MIN} .

The yield strength of the material is a function of pressure.

The specific form provided is shown in Figure II-1. If $P < P_{MIN}$, $Y = 0$.

If $P > P_{MIN}$ but $< P_V$, Y is calculated by interpolating along the lines shown. If $P > P_V$, Y is set to Y_V . This provides a Mohr-Coulomb

curve with a von-Mises limit of Y_V . Plasticity is checked by comparing Y to $\sqrt{3J_2}$. If $\sqrt{3J_2}$ exceeds Y all deviators are multiplied by $Y/\sqrt{3J_2}$.

This is the same flow rule used for metals and ignores any dilatancy in the material.

Initial bulk sound speed, c_0 is computed by assuming

$$c_0^2 = \frac{(1 + \nu)}{3(1 - \nu)} c_p^2$$

The Rigidity Modulus, or shear modulus, G , is computed from

$$G = \frac{3(1 - 2\nu)}{2(1 + \nu)} K$$

where K is the current bulk modulus. Provision is made for limiting G to an input value G_{max} .

Zone variables $BT1$ and $BT2$ are used to store the number of cycles that P is less than P_{MIN} and number of cycles during which the zone is plastic.

The built-in concrete equation of state is described in Appendix A to this report. It is designed for 5000 PSI concrete but can be changed to any strength by changing the value of FPC in subroutine $SETCONC$.

Density and other parameters can also be changed in the subroutine. The 5000 PSI model has been used to compute penetration of concrete at penetrator velocities from 800 to 1600 fps. It works very well for at least these cases.

A model has also been developed for 40 percent porosity dry sand from References 4 and 5. The P - u relationship is shown in Figure II-2. The sand is assumed to be a fluid with no yield strength. Input parameters (in CGS) are

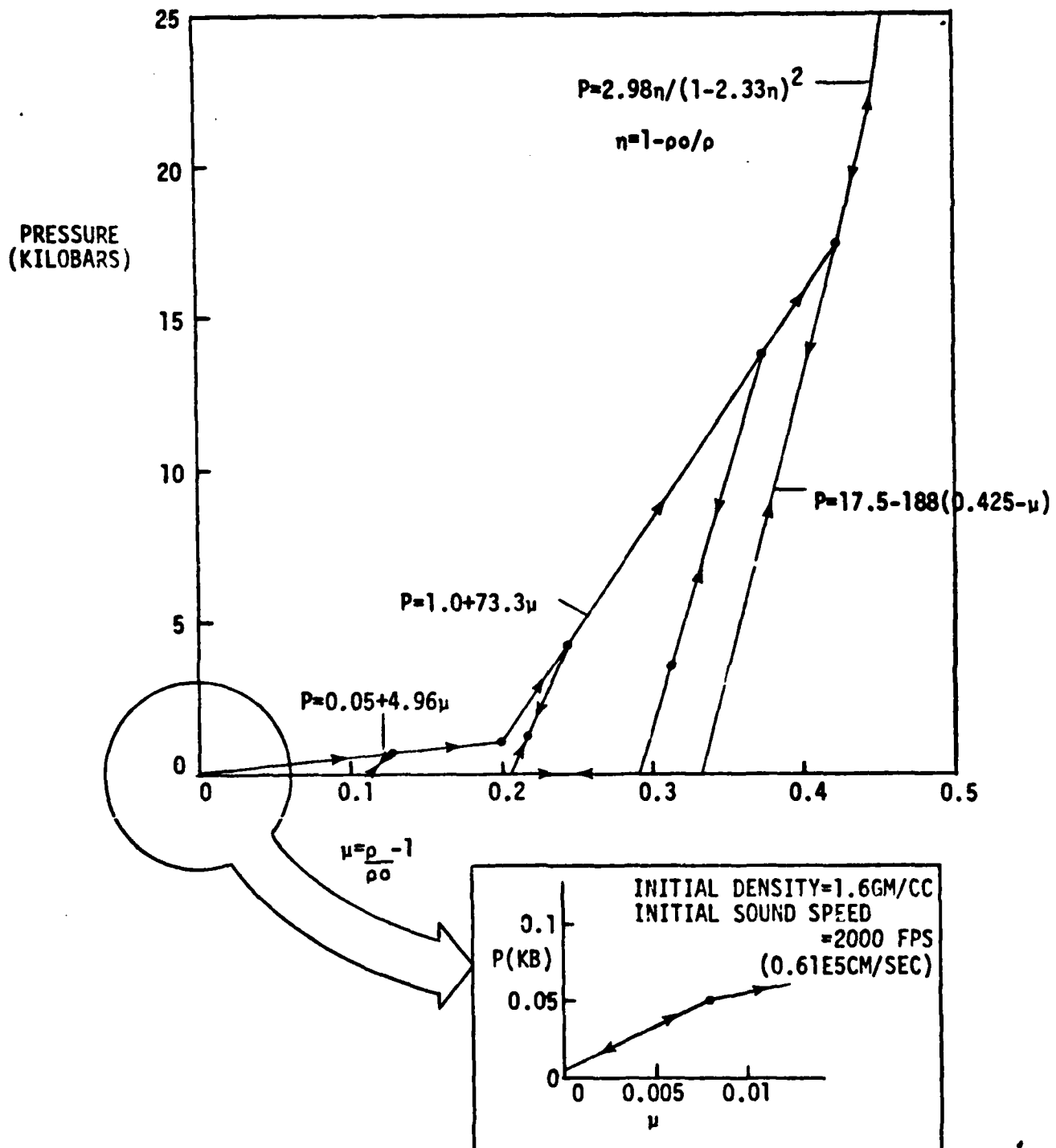
ρ_0	1.6
c_p	0.6096E5
PMIN	0
ν	0.5
PELAS	50.E6
PMID	1.E9
μ MID	0.2
PLOCK	17.5E9
μ LOCK	0.425
$c_{\delta L}$	0.441E5
S	2.33

The model has been used to calculate cavity size in underground HE detonations and has provided very good agreement with experiments in the Eglin AFB area.

FOAM (STATE 6)-SANDIA

EOS 6 provides a metal foam equation of state routine. It is the Sandia ALPHA-E model. Ref 2 describes the ALPHA-P model. The only

DRY SAND MODEL



REFERENCES

- A. "COMPENDIUM OF SHOCK WAVE DATA", UCRL-50108 (VOL 1), M. VAN THIEL, JUNE 1966.
- B. ALLEN, MAYFIELD AND MORRISON, 1957, J. APPL PHYS 28, pp 370-396.

FIGURE II-2

difference is that in the ALPHA-E model, P_e and P_s can be functions of the internal energy E . The specific forms provided are

$$P_e = H(E) P_{e0}$$

$$P_s = H(E) P_{s0}$$

where $H(E) = 1 - (k+2) \left(\frac{E}{E_0}\right) + (k+1) \left(\frac{E}{E_0}\right)^2$, K , E_0 , P_{e0} , P_{s0} are all input quantities. Generally, k should lie in the range

$$-2 \leq k \leq -1$$

There is no strength provided in this model.

GRAY METAL (STATE 7)-AIR FORCE

Equation of state 7 has been added to use the Grover And Young (GRAY) metal equations of state developed at the Lawrence Livermore Laboratory (Ref. 6). GRAY is a three-phase equation of state. It is coupled with State 1 rigidity modulus and yield strength options. Since the EOS is adequately explained in Reference 6, it will not be discussed here.

Table II-2 lists some input values required by the EOS and values as taken from Reference 6 for several metals. Units in the table are as they should be for input to TOODY. A Mie-Gruneisen EOS is used for the solid and liquid phases. The input variables c_0 and s define the Hugoniot and γ_0 and a define the Gruneisen parameter,

$$\gamma(\rho) = \gamma_0 - a n$$

The variable g_e is the electronic energy coefficient in Mbar-cc/mole-deg². The melting temperature, T_m , is calculated from a Lindemann law. T_{m0} , the melt temperature in deg K at $\rho = \rho_0$, is required as input. It is shown in Reference 6 that T_{m0} is approximately $1.3 \times T_{MN}$ where T_{MN} is the normal melting temperature. The variable AW is the atomic weight. R_j defines the ratio of volumes V_j/V_0 where V_j is the volume at which the EOS is joined to a modified van der Waals EOS for the vapor region. R_B is V_B/V_0 where V_B is the excluded volume for the vapor phase. The variable AY is a van der Waal's coefficient. TH is a join parameter explained in Ref 6.

In State 7, GRAY has been joined with the rigidity modulus and yield strength options of State 1. If an input variable TRFLAG is set to 1, then both Y and PMIN are reduced linearly to 0 at melt temperature.

State 7 uses the BT1 zone variables to indicate the phase of the material. BT1 = 0 means solid, 1 means melting, 2 means liquid and 3 means vapor. BT2 contains the ratio of current temperature to melt temperature.

TABLE II-2

GRAY INPUT

METAL	Po	C ₀	S	Y ₀	a	GE	T _{MO}	AW	RJ	RB	AY	TH
Mg	1.78	4.52E5	1.242	1.63	1.3	9.7E-9	1150	24.31	1.41	0.5	41	1.1
Al	2.79	5.33E5	1.338	2.18	1.7	8.7E-9	1220	26.98	1.32	0.53	47	1
Ti	4.52	4.7E5	1.146	1.3	1.1	10.1E-9	2260	47.9	1.43	0.58	68	1
Stainless	7.9	4.57E5	1.49	2.0	1.5	9.6E-9	2380	55.38	1.4	0.51	44	1
Ni	8.9	4.65E5	1.445	2.0	1.5	10.1E-9	2330	58.71	1.38	0.51	41	1
Cu	8.94	3.94E5	1.489	1.97	1.5	4.9E-9	1790	63.54	1.37	0.5	35	1
Ta	16.6	3.41E5	1.2	1.82	1.4	11.2E-9	4340	180.95	1.4	0.5	121	1
W	19.3	4.03E5	1.237	1.78	1.4	10.9E-9	4520	183.85	1.34	0.5	102	1
Pb	11.34	2.01E5	1.54	2.84	2.3	14.7E-9	760	207.2	1.24	0.48	49	1

SLURRY EQUATION-AIR FORCE

Equation of State 9 provides a detonation products equation suitable for slurry explosives. It was developed by personnel at the Lawrence Livermore Laboratory. It employs two JWL equations. About 25% of the slurry's total chemical energy is released upon detonation into the first JWL equation. Energy is then released on a time ramp into both JWL equations. During this phase the pressure contributed by each equation is proportional to the amount of energy released so that when all of the energy has been released pressure is provided by the second JWL equation only. The equations for State 9 are

$$P = F (1 - FR)P_1 + FR \cdot P_2$$

Where F is the burn fraction used in the first energy release and FR is a burn fraction used to release energy along a time ramp. P_1 is the pressure from the first JWL equation and P_2 is the pressure from the second JWL equation. These pressures are calculated from

$$P_i = A_i \left(1 - \frac{W_i R_{1i}}{\bar{\eta}}\right) e^{-R_{1i}/\bar{\eta}} + B_i \left(1 - \frac{W_i R_{2i}}{\bar{\eta}}\right) e^{-R_{2i}/\bar{\eta}} + W_i \rho E$$

Where $i = 1$ or 2 and $\bar{\eta} = \rho/\rho_0$

During the ramp burn, internal energy density E is increased by

$$EZ = EZDEL \cdot DT/T_{RAMP}$$

where $EZDEL$ is the amount of energy to be deposited on the ramp, DT is the time step and T_{RAMP} is the time spent, EZ is not allowed to exceed $EZDEL$. The time step is restricted during ramp burn to be no larger than $0.05DT_{RAMP}$.

The first burn fraction, F , is computed as for any explosive.
FR is computed as follows.

$$FR = 0 \text{ if } F < 1$$

$$FR = \text{MAX} (1, EZ/EZDEL) \text{ if } F = 1$$

State 9 uses zone variables BT1 and BT2 as follows. BT1 is FR.
BT2 is the amount of energy released to the current time, EZ.

ZONE VARIABLES-AIR FORCE

The zone variables have been changed somewhat from References 1 and 2. Three variables, BT1, BT2 and BT3 have been added bringing the total to 22. The deviatoric viscosity option has been dropped and those variables DQXX, DQXZ and DQZZ are used to store strain values. The zone variable lineup now is

MAT	Material indicator
X	Value of X coordinate
Z	Value of Z coordinate
UX	Velocity in X direction
UZ	Velocity in Z direction
TXX	Stress components. TYY
TYY	is hoop stress
TZZ	
TXZ	
Q	Artificial viscosity
DQXX	Strain Component, EXX
DQZZ	Strain Component, EZZ
DQXZ	Strain Component, EXZ
RHO	Density
C	Longitudinal Sound Speed
E	Internal energy density
AL	Area of zone in X - Z plane

XM Mass of zone
 BT Burn time if IES = 2
 Plastic work/unit volume if IES = 1
 and work hardening is being used.
 If IES = 1 and work hardening not used,
 then BT contains energy/unit mass to be
 deposited in the zone in time TDEP.
 If IES = 6, BT contains value of ALPHA,
 the distention ration
 BT1 Number of cycles a zone's pressure has
 had to be reset to PMIN
 If IES = 1 or 4
 BT2 Number of cycles a zone has been plastic
 IF IES = 1 or 4
 BT3 Hoop strain component, EYY

For boundaries ($MAT > 20$), only MAT, X, Z, UX and UZ are non-zero with the exceptions that for $MAT = 22$ the stress components carry the applied stresses and for boundaries along IT and JT only MAT and XM are non-zero (XM is -1 for these zones).

Zone positions and velocities are valid at the II, JJ intersection. Other zone quantities apply to the zone contained between II-1 and II and JJ-1 and JJ.

Strain components are not needed in TOODY to calculate stresses. They are saved merely as a convenience for plotting and editing purposes.

RESTARTING - AIR FORCE

RESTART FILE FORMAT

The restart file format has been changed. It is as follows

<u>RECORD</u>	<u>VARIABLES</u>
1	ID(1) through ID(9), NCYCLE, T, DT, IACT, IT, IHULLIN, ISPEC, NJVAR, IJ(1) through IJ(10), JMIN(1) through JMIN(10), JMAX(1) through JMAX(10).
2	JACT, JKACT (1)
If JACT GT 0 then the next record appears on the tape	
3	JKACT(2) through JKACT(IT)
4	NV, NOMAT, IALPH
If IHULLIN GT 0 then the next four records appear on the tape	
5	RPOS(1) through RPOS(200), YPOS(1) through YPOS(200), NSTN, NREC
6	NSTPT(1,1) through NSTPT(400,4), KBNDRY, KBDY(1,1) through KBDY(IT, JT) XAA(1, 1) through XAA(400, 4), ZAA(1, 1) through ZAA(400, 4)
7	HPEAK(1, 1) through HPEAK(200,4), HCURR(1, 1) through HCURR(200, 4)
8	PPRESS(1, 1, 1) through PPRESS(200, 2, 4), TPRESS(2), NPRESS1, NPRESS2 THULL

If ISPEC GT 0 then the next two records appear on the tape

- 1 ITREC,PTLAST(100) TLAST, EXX(100), EXZ(100)
 EZZ(100), ITNAT, NOSTA, ITPOS, MPTS(100), XXT0(100)
 ZZT0(100), EYY(100)
- 2 IITIME(1) through IITIME(ISPEC),
 JJTIME(1) through JJTIME(ISPEC),
 XTIME(1) through XTIME (ISPEC),
 ZTIME(1) through ZTIME (ISPEC),
 INUM(1) through INUM (10)

Each II column is a record. II = 1 through II = IT follow. Each record contains the 22 zone variables for JJ = JMIN (JTI) through JMAX(JTI) where JTI is the section number for the II column.

The last record on the dump is an end-of-file. Each dump therefore is separated by an end-of-file,

RESTARTING PROCEDURES - AIR FORCE

If RSMIN is greater than zero, TOODY will create restart dumps based on elapsed CP time or on problem time. Each dump is put on TAPE 25 in the initial run of the problem. Up to 20 files are allowed on TAPE 25. Subsequent dumps are put on TAPE 26 and then TAPE 27. After 20 dumps have been put on TAPE 27, TAPE 25 will be called again. There is no built-in tape length counter. For very large problems the 20 dumps allowed may be too many. If so, this must be changed at UPDATE line AFATL3.1 in the main routine. Normally, dumps are required so seldom that TAPE 25 is never filled.

When restarting, TAPE 25 must be positioned to the beginning of the correct dump. This can be accomplished in many ways - e.g., by using the correct number of COPYBF's in the control card deck. After restarting, further dumps are put on TAPE 26 (up to 20) and then TAPE 27. Finally, TAPE 25 will be called again.

To restart, the user puts in a blank ID line as the first card in input. Other cards should be input also. Changes can be made in non-zone variables such as material properties, TMAX, plotting input, etc. Zone variables such as material property indicators and mesh sizes can be changed only for columns greater than IACT + 1.

ZONING OPTIONS - AIR FORCE AND SANDIA

Input cards for each geometry region are as follows:

ISET

XO XCON(1), XCON(2), XCON(3), XCON(4), JMIN, JMAX

ZO ZCON(1), ZCON(2), ZCON(3), ZCON(4), IMIN, IMAX

ISET = 2, 3, 4, 5, and 6 have not been changed from References 1 and

2. ISET = 1 has been changed somewhat. In this option

$$X = XO + XCON(1)(JJ - JMIN) + (XCON(2) + XCON(3)(JJ - JMIN)$$

$$+ XCON(4) (Z - ZO)) (Z - ZO) + XCON(5) (II - IMIN)$$

$$Z = EZ + (ZCON(1) + ZCON(2) (JJ - JMIN)) (II - IMIN) + ZCON(5)(JJ - JMIN)$$

where $EZ = ZO$ if $ZCON(3) = 0$

and $EZ = ZO + 0.5 ZCON(3)(II - IMIN) (II - IMIN - 1)$

if $ZCON(3) \neq 0$

In the ISET = 1 option, XCON(5) is read in the JMAX field and ZCON(5) is read in the IMAX field.

Sandia has added an ISET = 7 option. In this option the boundaries of the region between IMIN, JMIN, IMAX, JMAX indices can be either straight line segments or arcs of circles, with the restriction that no arc may include an angle of 180° or larger. Mesh nodes on a line of constant JJ will be such that the arc length from the point at IMIN is

$$S_{II} = \left(\frac{II - IMIN}{IMAX - IMIN} \right) e^{X_I} S_{IT}$$

where S_{IT} is the total arc length of the line of constant JJ.

Similarly nodes on a line of constant II will be such that

$$S_{JJ} = \left(\frac{JJ - JMIN}{JMAX - JMIN} \right) e^{X_J} S_{JT}$$

The boundary arcs may be concave or convex. If they are concave, the input value of the radius is negative. For straight line boundaries, the input is a 0 radius. Three input cards are required. Input is

$X_0, X_1^*, X_2^*, X_3^*, X_4^*, JMIN, JMAX$

$Z_0, Z_1^*, Z_2^*, Z_3^*, Z_4^*, IMIN, IMAX$

$R_{12}, R_{23}, R_{34}, R_{41}, e^{X_I}, e^{X_J}$

If e^{X_I} or e^{X_J} are zero then the exponent will be a 1. See Figure II-3.

ISET = 8 is not used

ISET = 9 and 10 options have been added by the Air Force. ISET = 9 is used for regions with circles or $Z = \text{constant}$ lines along II columns and $X = \text{constant}$ lines along JJ rows.

Input is as follows:

X0 is X for center of II = IMIN circle

XCON(1) is Z for center of II = IMIN circle

XCON(2) is radius of the II = IMIN circle

If $II = IMIN$ is a straight line then the constant Z value for this line is $XCON(1)$. In this case $XCON(2)$ must be zero.

$XCON(3)$ is the value of X for $JJ = JMIN$

$XCON(4)$ is the value of X for $JJ = JMAX$

ZO is X for center of $II = IMAX$ circle

$ZCON(1)$ is Z for center of $II = IMAX$ circle

$ZCON(2)$ is radius for the circle at $II = IMAX$

If $II = IMAX$ is a straight line, then $ZCON(2)$ must be zero and $II=IMAX$ is a straight line along $Z = ZCON(1)$.

$ZCON(3)$ is any negative number if the center of the $IMIN$ circle is left of the $II = IMIN$ circular surface.

A positive or zero value indicates the center is to the right of the $II = IMIN$ surface.

$ZCON(4)$ Negative if center of $IMAX$ circle is left of the $II = IMAX$ surface.

Positive or zero if center is to the right.

$ISSET = 10$ is an additional shape option added to allow elliptical zoning. The ellipse must be centered at $(0, 0)$ and a full half of the ellipse must be modelled. The inner surface is $II = IMIN$ and has axes $XCON(1)$ in the X direction and $XCON(2)$ in the Z direction. The outer surface is $II = IMAX$ and has axes $XCON(3)$ and $XCON(4)$ in the X and Z directions respectively. If $ZCON(1)$ is non-zero then

II = IMAX is drawn with axes equal to those IMIN + ZCON(1) -- i.e., ZCON(1) is the thickness in this case.

ISET = 9 and ISET = 10 are also illustrated in Figure II - 3.

Initial velocity values are no longer input. Zero values are assumed for all materials. If non-zero values are desired they must be UPDATED into the SETUP 1 subroutine.

APPLIED PRESSURE BOUNDARY-AIR FORCE

The original Sandia TOODY offered a time varying applied pressure form. This has been taken out. If applied pressure is desired it can be taken from a HULL time history tape or a subroutine must be UPDATED into the code. The subroutine must begin with

SUBROUTINE PRESSIN (TIMEN,IPARG,PRESS)

TIMEN and IPARG are transferred into the routine and PRESS must be computed within the routine. TIMEN is the problem time. IPARG is the zone number - 1, 2, 3, or 4 (see Reference 1). PRESS must be negative if compression is desired and positive for tension. This is true because PRESS is really used as a stress input.

The largest change in applied pressure is that used to take stress values from a HULL time history tape (TAPE 9) and apply them to a TOODY problem. Also, since TOODY and HULL time history tapes are identical in format this means that a TOODY problem could be broken into separate problems connected by a pressure surface. It is implied in using this routine that shock impedance differences and TOODY boundary zone distortions are such that important physics

interactions are not lost in the decoupling.

The changes in TOODY required to use a HULL tape as input are quite extensive. The changes are not as general as would be desirable. A small amount of UPDATING must be employed to use HULL input.

The HULL time history tape format is as follows.

<u>RECORD</u>	<u>VARIABLES</u>
1	Two tape numbers (ignored by TOODY)
2	HULL ZBLK data (200 words). TOODY uses NOP = the number of particles in the HULL problem (particles can be tracers or time history station locations) NPP = the number of position values needed to describe a particle's location (2 for two dimensions) NSTN = The number of time history stations.
3	This record contains (R, Y) position pairs for the NOP particles and is NOP x NPP long. <u>NOTE:</u> TOODY assumes NOP x NPP is no larger than 1024. If more room is needed, then the dimensions on the array AHULL must be increased in the HULLII common block. The dimension in AHULL must never be less than 1024. Lower bits of the R and Y words are examined to determine if the particle is a station and,

if so, its number. TOODY also assumes no more than 200 stations. If more are needed RPOS and YPOS dimensions must be changed in HULLII.

4 Each record from record number 4 on contains
. time history data. The first word is T.
. (time) with NW (the number of words of data
. for that time) masked into the lower bits of
T. Since there are 15 variables saved per station, the number of stations with data at time T is NW/15. Masked into the lower bits of the first of the 15 variables is the station number. Stresses are contained in variables 7 (radial stress), 8 (Shear stress), 9 (axial stress) and 10 (hoop stress).

Subroutine POSREAD is called from PRESET and reads the first 3 HULL records if TOODY input variable IHULLIN is Set to 1. It adds RHOFF and YHOFF to HULL R and Y station positions. RHOFF and YHOFF are input to TOODY and are offsets between the HULL and TOODY Coordinate systems.

Subroutine PREAD fills the PPRESS (200, 2, 4) and TPRESS(2) arrays from HULL data. PPRESS contains station pressures at two times, TPRESS(1) and TPRESS(2). These two times are such that TOODY time is contained at a point between them. The first dimension in PPRESS is the HULL station number. The second identifies the time - either

TPRESS(1) or TPRESS(2). Variables NPRESS1 and NPRESS2 are used in a flip-flop manner to keep up with time. The earliest time is contained in TPRESS(NPRESS1). The latest time is in TPRESS(NPRESS2). Initially NPRESS1 = 1 and NPRESS2 = 2. To avoid copying of PPRESS from one time to the next, NPRESS1 and NPRESS2 are flip-flopped. When a new time is needed it and stress data are read into TPRESS and PPRESS at NPRESS1, since that data is no longer needed. Then NPRESS1 and NPRESS2 exchange values. The second dimension in PPRESS identifies time and is either NPRESS1 or NPRESS2. The third dimension identifies the stress component. Radial stress is 1, shear stress is 2, axial stress is 3 and hoop stress is 4.

TOODY must identify the HULL stations (one for corners and two otherwise) which define pressure for each applied pressure zone. This coding has not been generalized and must be rewritten for each problem. Each TOODY zone requiring pressure input is identified in an array KBDY(II, JJ). For any (II, JJ) the value of this array KBNDRY = KBDY (II, JJ) is a key number needed to identify the HULL stations providing input to that TOODY zone. KBDY is dimensioned to (IT, JT) by the preprocessor. The II, JJ values in KBDY must be those of the zone being processed through the momentum routine in TOODY MAIN. These are zones which define the physical boundary in the applied pressure region. The HULL stations identified with this boundary point are contained in the array NSTPT (400, 4). Two stations are encoded in a 2I5 format in the NSTPT word. The limit

of 400 means there can be no more than 400 TOODY zones requiring HULL input. The second dimension in NSTPT is IPARG and identifies the surrounding zone as 1, 2, 3 or 4 (See Reference 1). KBNDRY is also used to find the average X and Z values in TOODY along the boundary of the zone subjected to applied pressure. These values are contained in XAA (400, 4) and ZAA (400, 4). The second dimension is again IPARG. These numbers are required because TOODY weights input from the two HULL stations by using range from (XAA, ZAA) to the HULL station positions. Initial values of XAA and ZAA are saved at setup time and used for weighting so that distortions of the TOODY grid cannot change the weighting functions.

It is necessary to consider an example to understand how this fairly complex system really works. Suppose TOODY is modelling a cylinder subject to pressure from a HULL calculation. The mesh for this is shown in Figure II-4a. It is 7cm long and 5cm in radius. TOODY models just one half of the cross-section of the cylinder and sets IALPH = 2 so that the Z axis is an axis of rotation. The physical boundaries of the cylinder are at II = 1, II = 6 and JJ = 1 and JJ = 4. Material numbers are shown in II - 4b. The material indicator input cards for this problem would be

KM	IS1	IS2	JS1	JS2
1	2	6	2	4
22	1	1	2	4
22	7	7	2	4
22	1	7	5	5
23	1	7	1	1

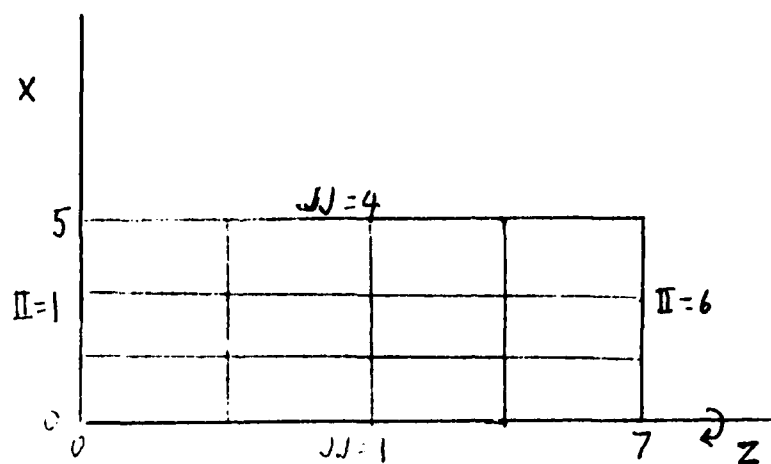


FIGURE II-4a

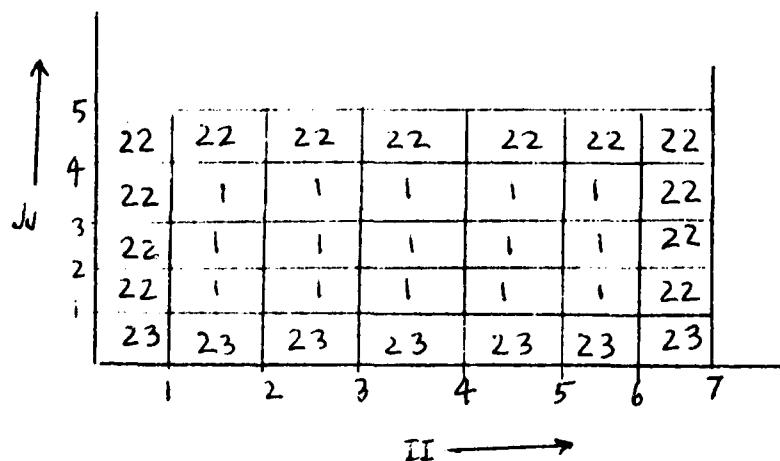


FIGURE II-4b

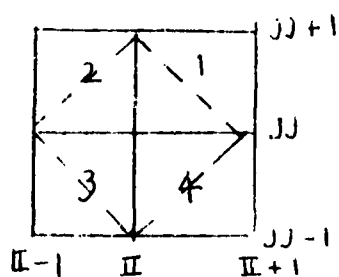


FIGURE II-4c

Symmetry (MAT = 23) is used along the centerline (JJ = 1). The other boundary zones are applied pressure (MAT = 22). IT is 7 and JT is 5 because one additional II and one additional JJ line must be provided to carry boundary indicators. The II = 6 and JJ = 4 physical boundary lines contain the material number for the actual cylinder material. The momentum routine will process II=1 through II=6. For each II value it will process JJ values from 1 through 4. It will not look at II = 7 or JJ = 5 lines. For each (II, JJ) the momentum routine requires values of stress, density, etc for the four zones surrounding the point. This is shown in Figure II - 4c. The zones surrounding (II, JJ) are numbered as shown in the figure. The dashed line indicates the boundaries of the diamond-shaped momentum zone. If all four zones contain real material - in this case material 1 - then the applied pressure routine (ENTRY PRESURE in SUBROUTINE OUTPUT) is not called. If any of the zones contain a 22 indicator then it is called with IPARG being the zone number of the zone requiring pressure data. For example, consider that TOODY is processing the point II = 1, JJ = 3. Then material numbers in the four zones are as shown in Figure II - 4d. Zones 1 and 4 contain real material. Zones 2 and 3 are boundary zones requiring applied pressure. PRESURE will be called with IPARG = 2 and then it will be called again with IPARG = 3. Figure II - 4e shows another possible situation. In this case II = 1 and JJ = 4 - a corner point. Data is required in this case for three zones, IPARG = 1, 2 and 3. Along JJ = 4 data will be needed for zones 1 and 2 (See figure II - 4f). At the other outer corner, II = 6 and JJ = 4,

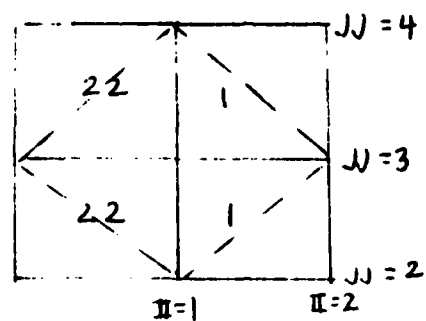


FIGURE II-4d

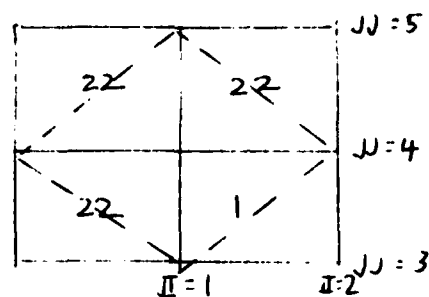


FIGURE II-4e

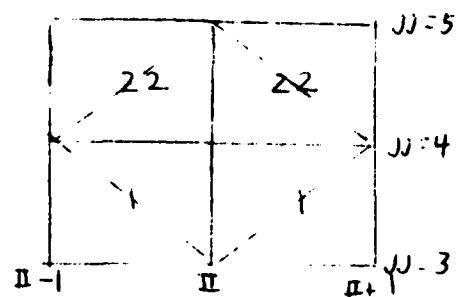


FIGURE II-4f

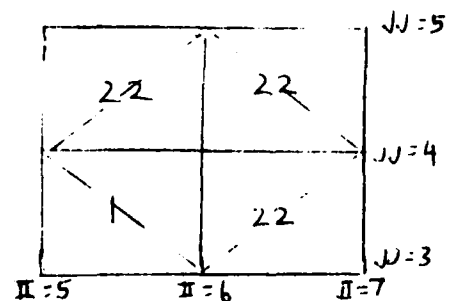


FIGURE II-4g

pressure is needed for zones 1, 2 and 4 (Figure II - 4g). Along II = 6, at mid JJ values such as 3, data is needed for zones 1 and 4 (Figure II - 4h). Pressure data will not be required along JJ = 1, the bottom boundary, except at the corners. For example, at II = 1, JJ = 1 material indicators are as shown in Figure II - 4i. Since II = 1 is an axis of symmetry, PRESURE will be called for both zone 2 (IPARG = 2) and zone 3 (IPARG = 3). If there is no shear stress, then the stress transferred is the same for both zones. The shear stress component must be reversed in sign if it is non-zero. The same comments apply to the corner at II = 6 and JJ = 1 with the exception that the zones have material indicators as shown in Figure II - 4j.

We have identified the zones in this sample problem requiring applied pressure input from HULL. The user must provide coding to identify the NSTPT, XAA and ZAA arrays. SUBROUTINE SETUP contains a routine to provide these needed variables for a particular problem. It can be modified or a new routine written. For illustration, the coding required to modify it for this sample problem will be discussed. HULLIN.55 through HULLIN.84 can be deleted and replaced by

```

DO 5900 II = 1, ITEND
  ICT = NV * JMAX(1)
  DO 5003 IPP = 1, ICT
5003  IC (IPP, 1) = IC(IPP, 2)
    DO 5004 IPP = 1, ICT
5004  IC (IPP, 2) = IC (IPP, 3)
    BUFFER IN (NTP1, 1)(IC(I,3), IC(ICT,3))
    IF (UNIT (NTP1)) 5005, 5005, 5005
5005  CONTINUE

```

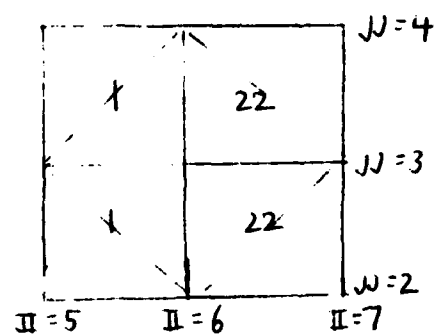


FIGURE II-4h

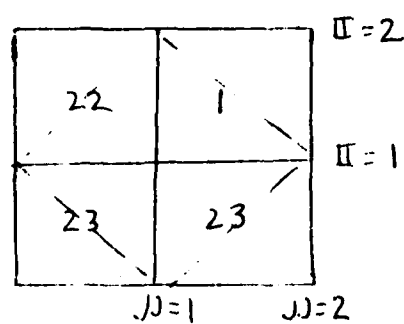


FIGURE II-4i

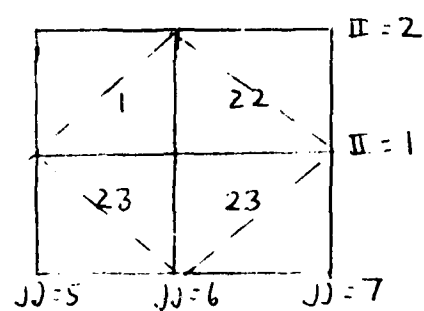


FIGURE II-4j

This coding will put the II - 1 column in IC (-, 1), II in IC (-, 2) and II + 1 in IC (-, 3) for each II value. HULLIN.85 through HULLIN.90 can be replaced by

```

JT1 = JMAX(1)
DO 5890 JJ = 1, JT1
M = NV * (JJ - 1) + 1
IF (II .EQ.1) GO TO 5006
IF (JJ .EQ.4) GO TO 5006
IF (II .EQ.6) GO TO 5006
GO TO 5890

```

For each (II, JJ) point requiring NTSPT, XAA and ZAA data, the coding sends the computer to statement 5006. Statement 5006 will begin special coding to provide NTSPT, XAA and ZAA values for IPARG = 1 through 4 as needed. HULLIN.101 through HULLIN.132 must be replaced. This coding, inside a DO LOOP on IPARG provides average X and Z values for each boundary zone, XAVG and ZAVG, and also provides X and Z values, XX1 and ZZ1, which lie along the boundary line. XAVG and ZAVG will be stored later as XAA and ZAA. The (XX1, ZZ1) values will be used to define a normal to the boundary line. This normal is needed to allow the code to find the nearest two HULL stations. Subsequent coding will assume that corners (where only one station is desired) will be identified by values of XX1 = 777. The replacement coding could be

```

GO TO (5010, 5020, 5030, 5040),IPARG
5010 IF (II .LE.5. AND. JJ .EQ.4) 5011, 5012
5011 XAVG = 0.5*(X(M, 2) + X(M,3))
ZAVG = 0.5* (Z(M, 2) + Z(M, 3))
XX1 = X(M, 3)

```

```

ZZ1 = Z(M, 3)
GO TO 5300
5012 IF (II . EQ. 6. AND. JJ. EQ. 4) 5013, 5014
5013 XAVG = X(M,2)
ZAVG = Z(M, 2)
XX1 = 777
GO TO 5300
5014 IF (II. EQ.6) 5015, 5300
5015 XAVG = 0.5* (X(M,2) + X(M + NV, 2))
ZAVG = 0.5* (Z(M, 2) + Z(M + NV, 2))
XX1 = X(M + NV, 2)
ZZ1 = Z(M + NV, 2)

```

Coding for IPARG = 2, 3 and 4 would follow but will not be shown here. The coding above, combined with that already in SETUP will send the code to statement 5300 with (XAVG, ZAVG) and (XX1, ZZ1) values set to those needed for each physical boundary zone and each value of IPARG. The remaining coding in SETUP will handle the rest of the problem automatically.

The only further complication occurs with slide lines. Slide lines cause two problems. Slide lines can be the last line in a section, $II = IJ(JTI)$, or the first line in the next section, $II = IJ(JTI) + 1$ (the latter is recommended). Whichever is used, the slide line is co-located in space with another line which provides the other side of the slip surface. This can complicate the SETUP coding needed to set the NTSPT, XAA and ZAA array values. The

second problem occurs if a slide line on the other side of the slip surface actually provides an applied pressure surface. For example, consider Figure II-5. In this case the slide line is $II = 4$ and its neighbor $II = 3$ has a portion of itself extending into the HULL flow field. The TOODY slide routine was written by Sandia to be very general, but does not properly handle this case without modifications. When processing $II = 3$ and $JJ = 1$ through 4 zones, TOODY may assume a free surface boundary since one side of the slide line extends further than the other. This can be fixed quite simply by adding a few lines of coding to the SLIDE subroutine. In this case, coding can be added in ENTRY SLIDE 2. The coding to be added would be

```
* DELETE TOODY3.5280
```

```
IF (DO(JJ) - DIMIN.LE.ZERO) K4 = IC(M,IP) = 22
```

and * DELETE TOODY3. 5282

```
IF (DO(JJ + 1) DIMIN.LE.ZERO) K1 = IC(I,IP) = 22
```

DO and DIMIN are discussed in Reference 1.

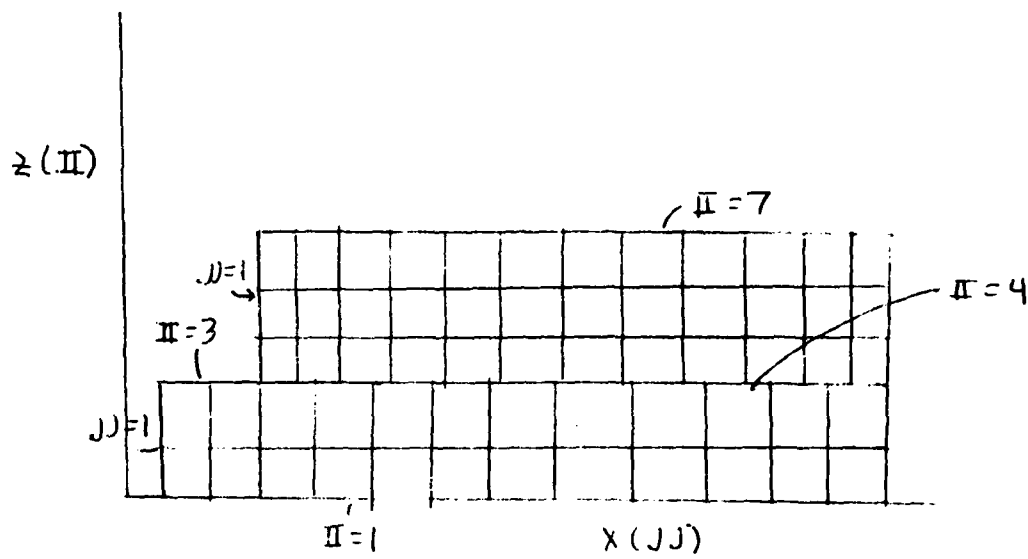


FIGURE II-5

PLOTTING-AIR FORCE

Grid, velocity vector and zone variables vs X type plotting routines have been built into TOODY. The routines use only a small amount of central memory and are highly flexible. In addition, they can be easily changed to provide specialized plots such as warhead fragment angles vs radial position of the fragments. They are written in SC 4020 language.

The plots are divided into two general types. The input variable IGRID provides GRID plots which include

- (1) Distorted grid plots
- (2) Velocity vector plots with material and physical boundaries shown
- (3) Material and physical boundary plots with BT1 or BT2 values printed in zones in which these values exceed 0.

The routine can be easily modified to print peak pressure, maximum tensile strain, etc. The second type of plot is controlled by the input variable IGRAF and provides GRAPH plots. These are plots of zone variables vs X. One plot can contain plots for several II columns. The plots are restricted to plots vs X because of the way in which data is stored on intermediate files TAPE 21 and TAPE 22. Generally X increases with JJ. The plotter brings in one II column at a time and can easily plot any variable as it changes with JJ values. To plot along a constant JJ row with II varying would require an inordinate amount of computer time. These routines will now be discussed in detail and examples shown.

GRID PLOTTING

The total number of grid plots to produce at any time is IGRID. Problem times for plotting are controlled by TGRDDEL. It is assumed that plots are desired at $T = 0$, $T = \text{TGRDDEL}$, $T = 2 \text{ TGRDDEL}$, ..., through the end of the problem. TGRDMIN can be used to start grids at a problem time other than 0 and TGRDMAX can be used to cease plotting at a certain problem time. These are now set automatically at 0 and 1E6 seconds respectively. Changes to these values must be made by UPDATING new values into subroutine READGRD (which reads in GRID plotting control variables). Input variables for each plot desired, from 1 to IGRID, are on two cards. The first is

IGRDMIN, IGRDMAX, JGRDMIN, JGRDMAX, IOPTION

the second card is

XGRDMIN, XGRDMAX, ZGRDMIN, ZGRDMAX, XHORIZ

IGRDMIN, IGRDMAX, JGRDMIN and JGRDMAX are bounding values of II and JJ to be included in the plots. These variables allow the user to plot specific portions of the grid -- he need not always plot the entire grid. IOPTION controls the type of plot. IOPTION = 0 means a plot showing all grids within the bounding indices. IOPTION = 1 means plot velocity vectors. IOPTION = 2 means place values of BT2 (plastic counter) in zones which do not use equations of state 2 or 3 or 6. IOPTION = 3 means place values of BT1 (PMIN counter) in zones which do not use states 2 or 3. XHORIZ controls which variable, X or Z, will be the horizontal axis on the plots. XHORIZ = 0 means the X axis is

the horizontal axis. XHORIZ = 1 means Z is horizontal. XGRDMIN, XGRDMAX, ZGRDMIN, ZGRDMAX define the min and max coordinates for the plot. OPTION(1), OPTION(2) and OPTION(3) control velocity vector plots. They are not input variables in that they are automatically set to 0. They can be changed only through UPDATE. Zero values for these variables provide reasonable defaults. OPTION(3) is the minimum value of velocity to display. The default value is 1. OPTION(1) and OPTION(2) control the size of the maximum velocity vector on the plot (max for all the grid not just that on the plot). OPTION(1) controls the X velocity component. OPTION(2) controls Z. They are mapping variables and are set to the velocity values desired for 76 raster points (0.5 inches on the SC4020 plotter). Normally the two are equal. Independent controls are provided so that velocity vectors can have their proper angles even if XGRDMAX - XGRDMIN is not equal to ZGRDMAX - ZGRDMIN. Default values are such that the max velocity is 0.5 inches long.

On cycle 0, or the first cycle after a restart, HULL boundary stations (if any) are shown on all grid plots using the letter H at the station location. At the same time TOODY time history locations are shown with their station numbers.

Figures II-6 and II-7 are examples of grid and velocity vector plots.

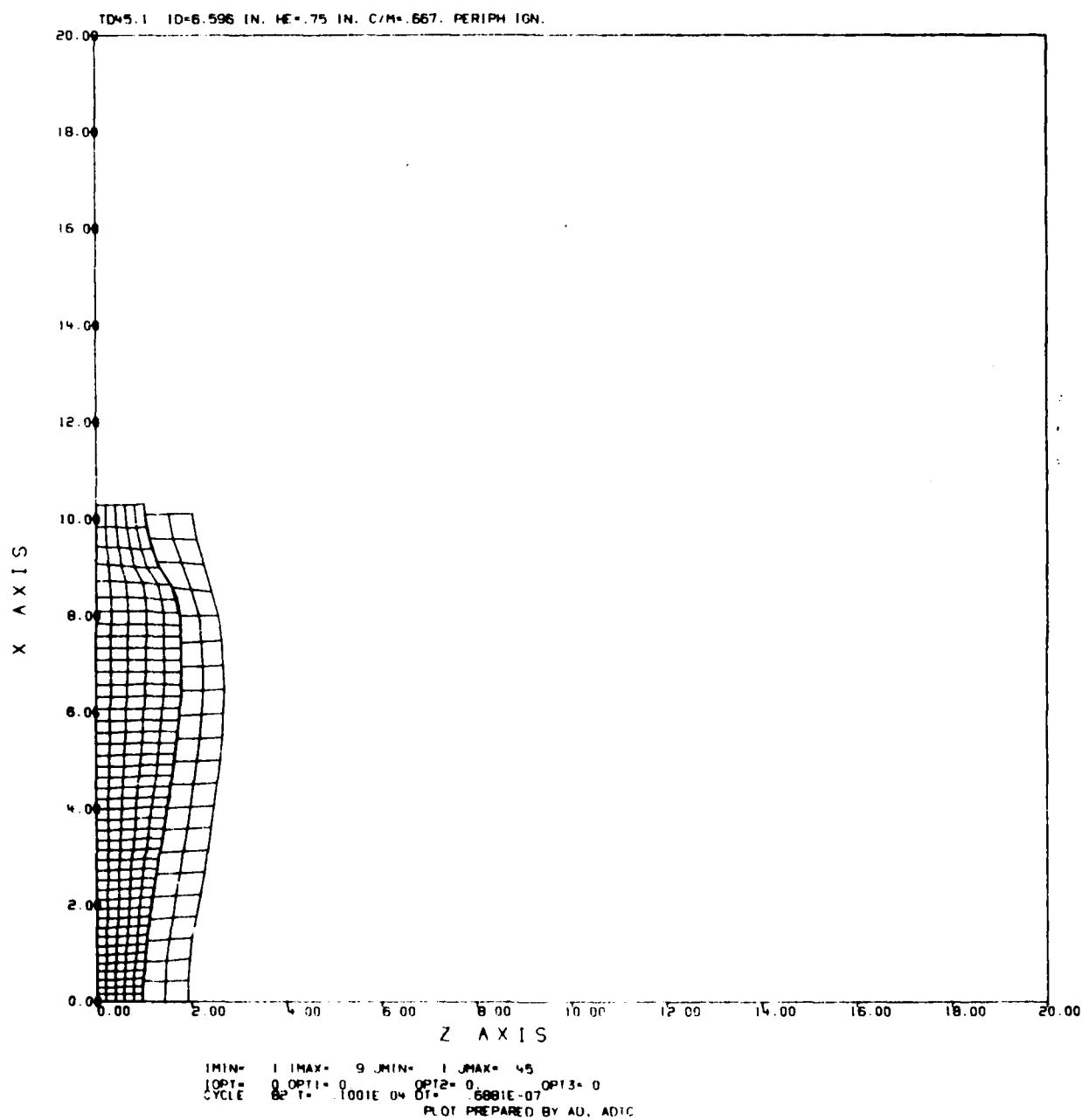


FIGURE II-6

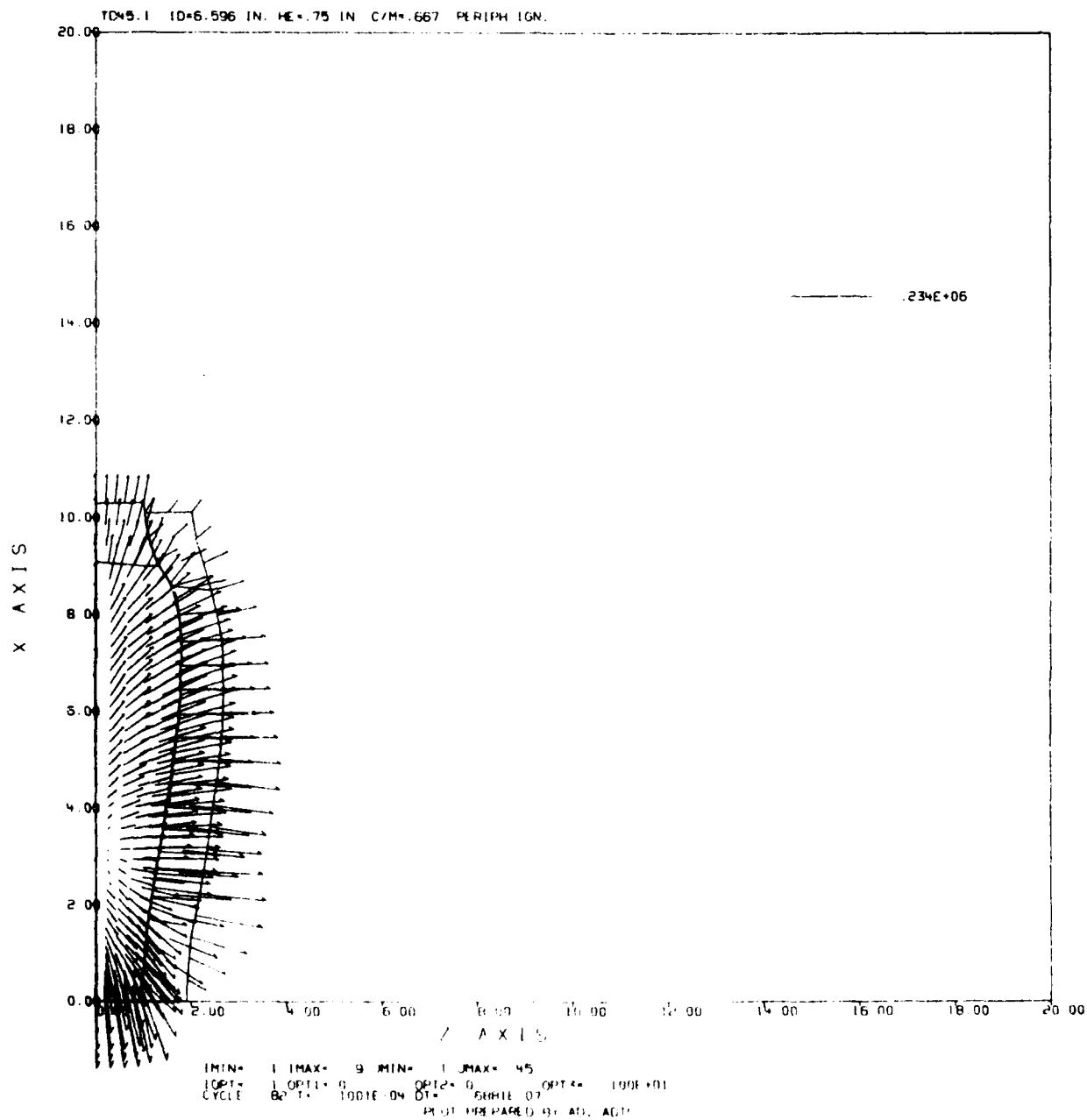


FIGURE II-7

GRAPH PLOTTING

If IGRAF is greater than 0, GRAPH plots occur at problem times TGRFMIN, TGRFMIN + TGRFDEL, TGRFMIN + 2 TGRFDEL, ..., TGRFMAX. The user inputs TGRFMIN and TGRFDEL. TGRFMAX is set at 1.E6. To change TGRFMAX the user must UPDATE in a new value in SUBROUTINE RDGRAF. Each plot, from 1 to IGRAF, must have two input cards specified. The first is

IGRFMIN, IGRFMAX, IGRFDEL, JGRFMIN, JGRFMAX

the second is

OGMIN, OGMAX, IORDGF

Each plot will consist of the variable specified by IORDGF being plotted vs X values between JGRFMIN and JGRFMAX for II columns, IGRFMIN, IGRFMIN + IGRFDEL, IGRFMIN + 2IGRFDEL, ..., IGRFMAX. The II value is indicated on each curve. The ordinate min and max values are OGMIN and OGMAX. If these are zero, the code finds min and max values automatically. IORDGF values and the variables plotted are

<u>IORDGF</u>	<u>VARIABLE</u>
4	X
5	Z
6	UX
7	UZ
8	TXX
9	TYX
10	TZZ
11	TXZ
12	Q
13	EXX (really DQXX)
14	EZZ (really DQZZ)
15	EXZ (really DQXZ)
16	RHO
17	C (longitudinal sound speed)
18	E
19	AL (zone area)

20	XM (zone mass)
21	BT
22	BT1
23	BT2
24	BT3 (normally hoop strain)
25	Total velocity
26	Pressure

Figures II-8 and II-9 are examples of GRAPH plots. In these examples, the routines were modified to plot total velocity in FPS vs initial radial position, X, and velocity angles with respect to the Z axis (THETA) vs initial radial position. To do this the array DQXX was used to contain initial X and DQXZ was used to contain velocity angle. Then we simply plotted velocity vs DQXX and DQXZ vs DQXX. GRAPH was UPDATED slightly to change velocity and position units to FPS and inches. The X calls in GRAPH were changed to DQXX calls. XLAB and YLAB, abscissa and ordinate labels were changed in GRAPH. DQXX was set in SETUP 1 after statement 395. DQXZ was set after statement 970 in MAIN by using the call

```
CALL SUBANG (UX(M, INN), UZ(M, INN), DQXZ(M, INN))
```

SUBANG is a built-in utility routine which computes angle in degrees between the velocity vector and the positive Z axis. The angle returned varies from -90 through 270 degrees. Of course, the coding in MAIN setting DQXX to EXX and DQXZ to EXZ had to be deleted. In addition coding after statement 500 in SETUP 1 had to be changed so that DQXX would not be made zero (after it had been set to initial X values after statement 395). A little practice will allow the user to plot virtually any variable vs any other variable which changes with JJ values. The utility Subroutine PRINC may be helpful in this regard. It returns maximum and minimum principal stresses or strains

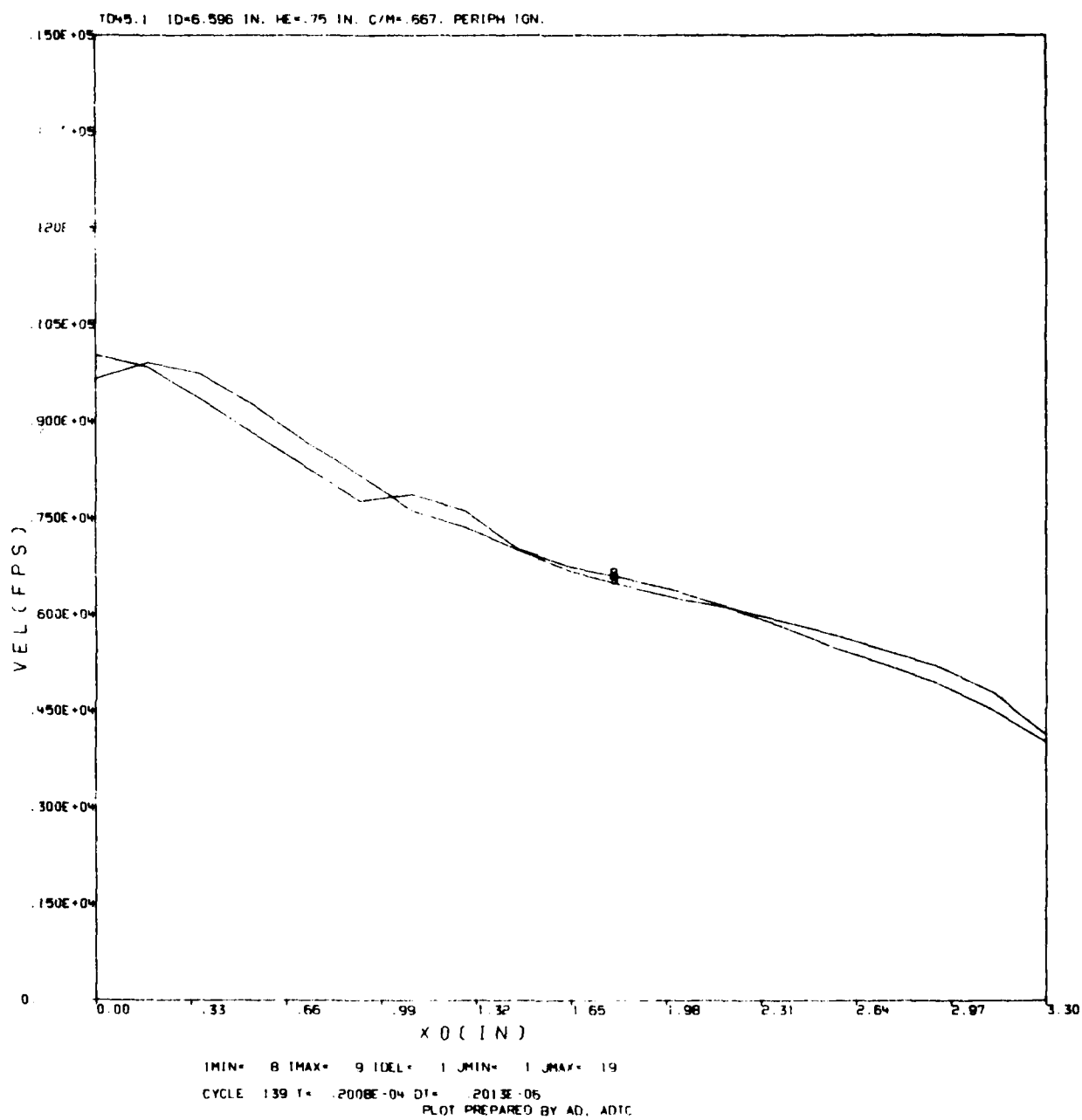


FIGURE II-8

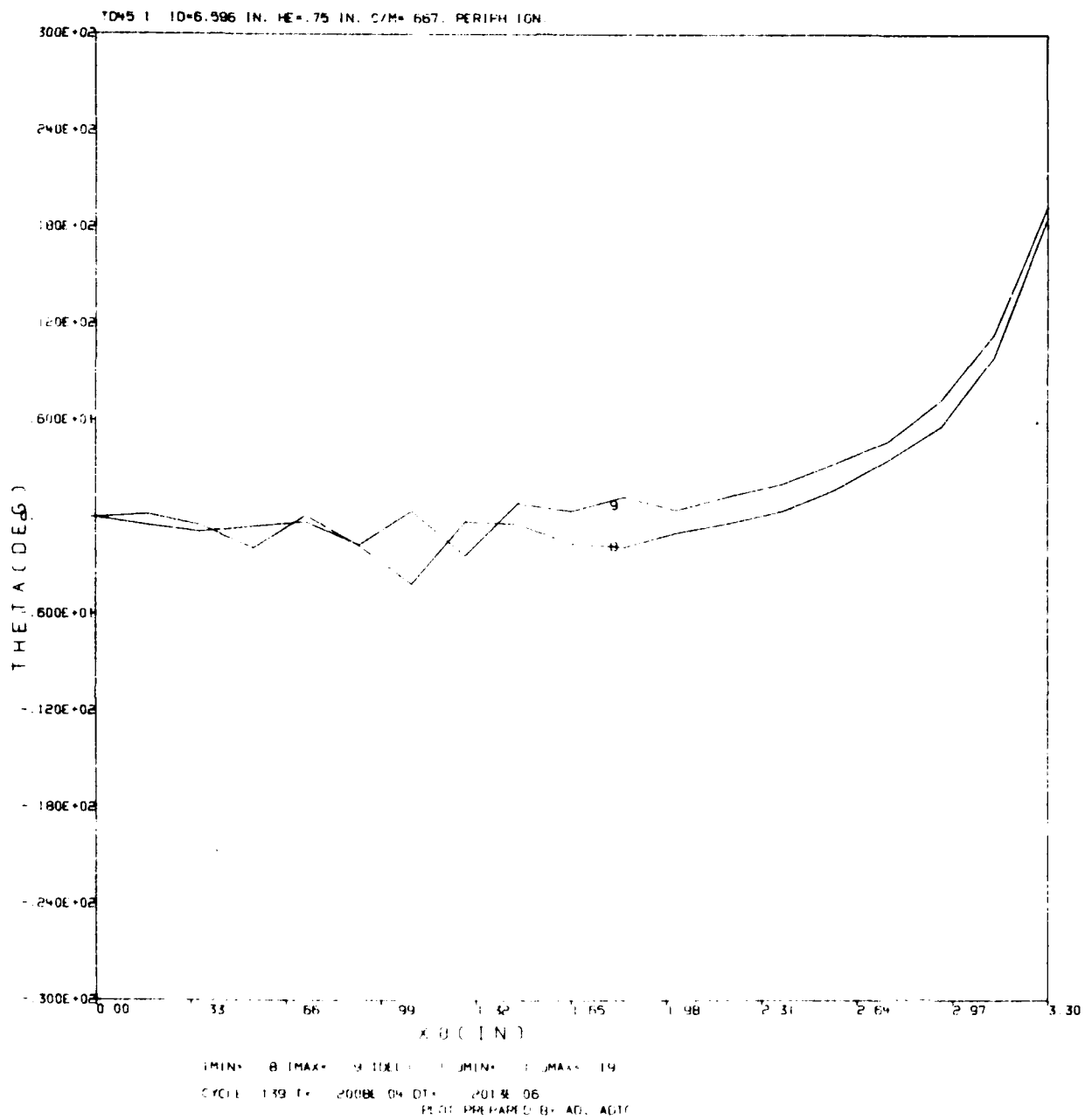


FIGURE II-9

given the XX, ZZ and XZ values. It can be called as follows.

CALL PRINC (XX, ZZ, XZ, E1, E2, ES)

where XX, ZZ and XZ are given stress or strain component values.

E1 is the maximum stress or strain, E2 is the minimum and ES is the maximum shear.

TIME HISTORIES-AIR FORCE

Routines have been added to allow the user to save time history information for TOODY zones on TAPE 12. This information can then be plotted using the HULL station plotter in program PULL or other plotting routines available from AFATL/DLJW. Time history data is saved in the same compact format used by the HULL code. This technique has been shown to be very efficient in time, memory and tape requirements.

Time histories are controlled by the input variable ISPEC. ISPEC should be set to the number of stations desired. One card must be input for each station from 1 to ISPEC. The card contains

IITIME, JJTIME, XTIME, ZTIME

where (IITIME, JJTIME) are the (II, JJ) values for the station and (XTIME, ZTIME) are the stations' (X, Z) values. The code expects that either (II, JJ) or (X, Z) will be specified. The unspecified set is filled in by the code in SETUP1.

The following data is saved at each station (in the order shown)

- 1 -- Density with station number in the lower bits
- 2 -- Radial displacement
- 3 -- Radial velocity
- 4 -- Axial velocity
- 5 -- Radial acceleration
- 6 -- Axial acceleration
- 7 -- Radial stress
- 8 -- Shear stress
- 9 -- Axial stress
- 10 -- Hoop stress
- 11 -- Radial strain
- 12 -- Shear strain
- 13 -- Axial strain
- 14 -- Hoop strain
- 15 -- Axial displacement

If plane geometry is used ($IALPH = 1$) then radial components are X components. Strains are computed in the time history routines and are independent of zone variables DQXX, DQXZ, DQZZ and BT3. These zone variables can be used for other purposes and strains can still be obtained using time histories. Displacements are computed by assigning initial X and Z values, XXTO and ZZTO, to each station. The code assigns these values as the node point values for (IITIME, JJTIME). Displacements are then computed by determining nodal X. Z changes. Thus displacements are independent of any (XTIME, ZTIME)

settings. The (XTIME, ZTIME) values are used only as position indicators on the plots. If defaulted to zero, these (XTIME, ZTIME) values are set to mid-point in the (IITIME, JJTIME) zone.

Data is saved for any station whenever total acceleration has changed from the last value saved by 0.2 percent. XX stress is used instead of acceleration for an applied pressure zone. Data is packed in records of 1024 words length.

Dimensioning in common block THIS1 assumes no more than 100 stations.

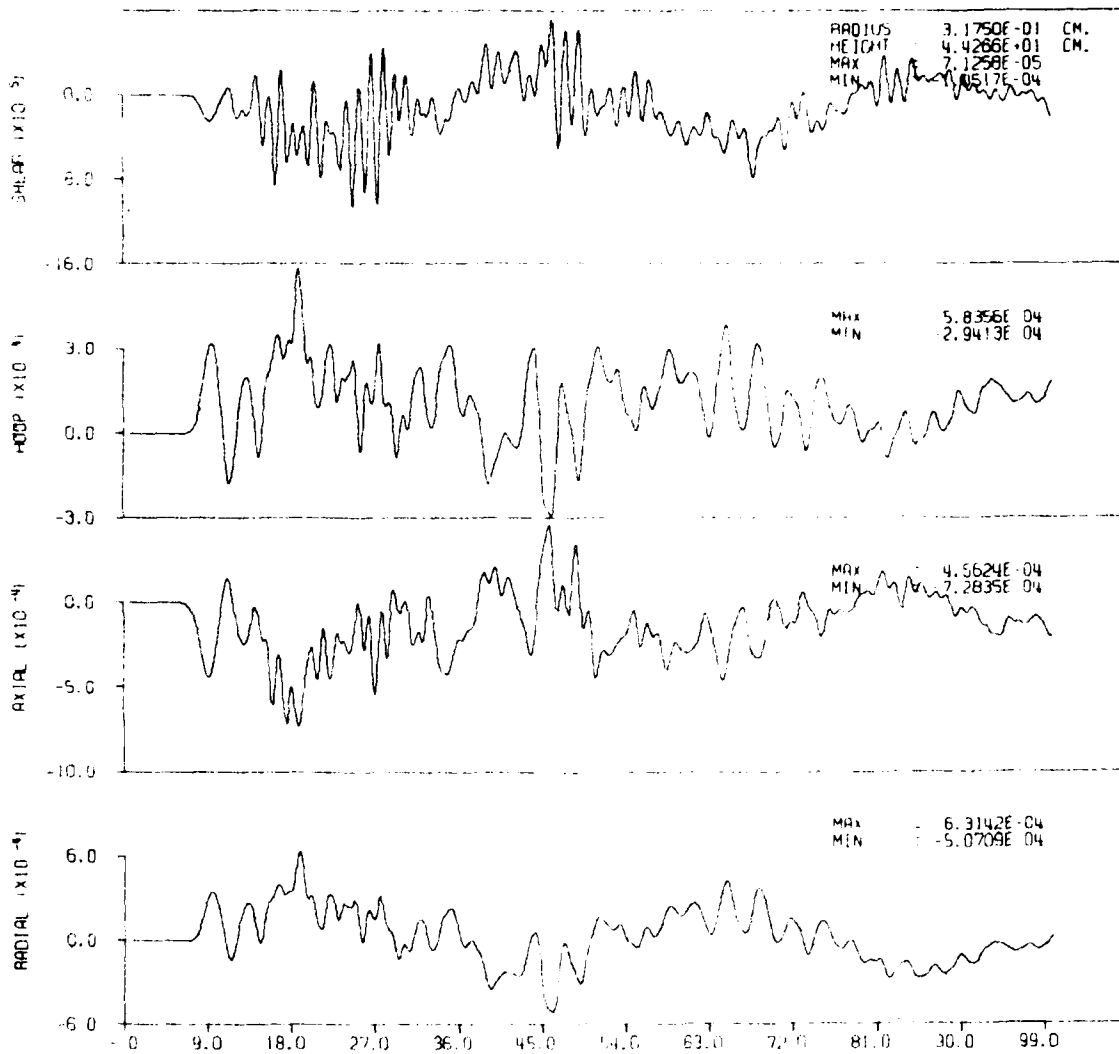
Figures II-10 through II-16 show the results of using the PULL plotter with a TOODY station tape. (PULL was modified by Ms Cydney Westmoreland to plot the 15 variables in the format shown in the figures).

UTILITY ROUTINES-AIR FORCE

Utility routines SUBANG and PRINC have already been discussed.

Utility routine FPDUMP, written primarily by Mr Harold Iuzzolino while at the Air Force Weapons Laboratory, provides decimal dumps whenever errors occur. It relies on system subroutines RECOVER and PDUMP. It is called whenever a mode error occurs. Subroutine EREXIT has a division by zero built into it, so FPDUMP is called also whenever EREXIT is called. FPDUMP prints out the location of the error, the values of all registers and the first 100 code words, II, JJ, NCYCLE and T when called and the values of major COMMON blocks and the IC columns. As now set up it skips dumping general coding

STRAIN COMPONENTS



1000Y 21.3 CROM WITH RECURSIVE. COMPLETE STRESS TENSOR.

PROBLEM 0.0000

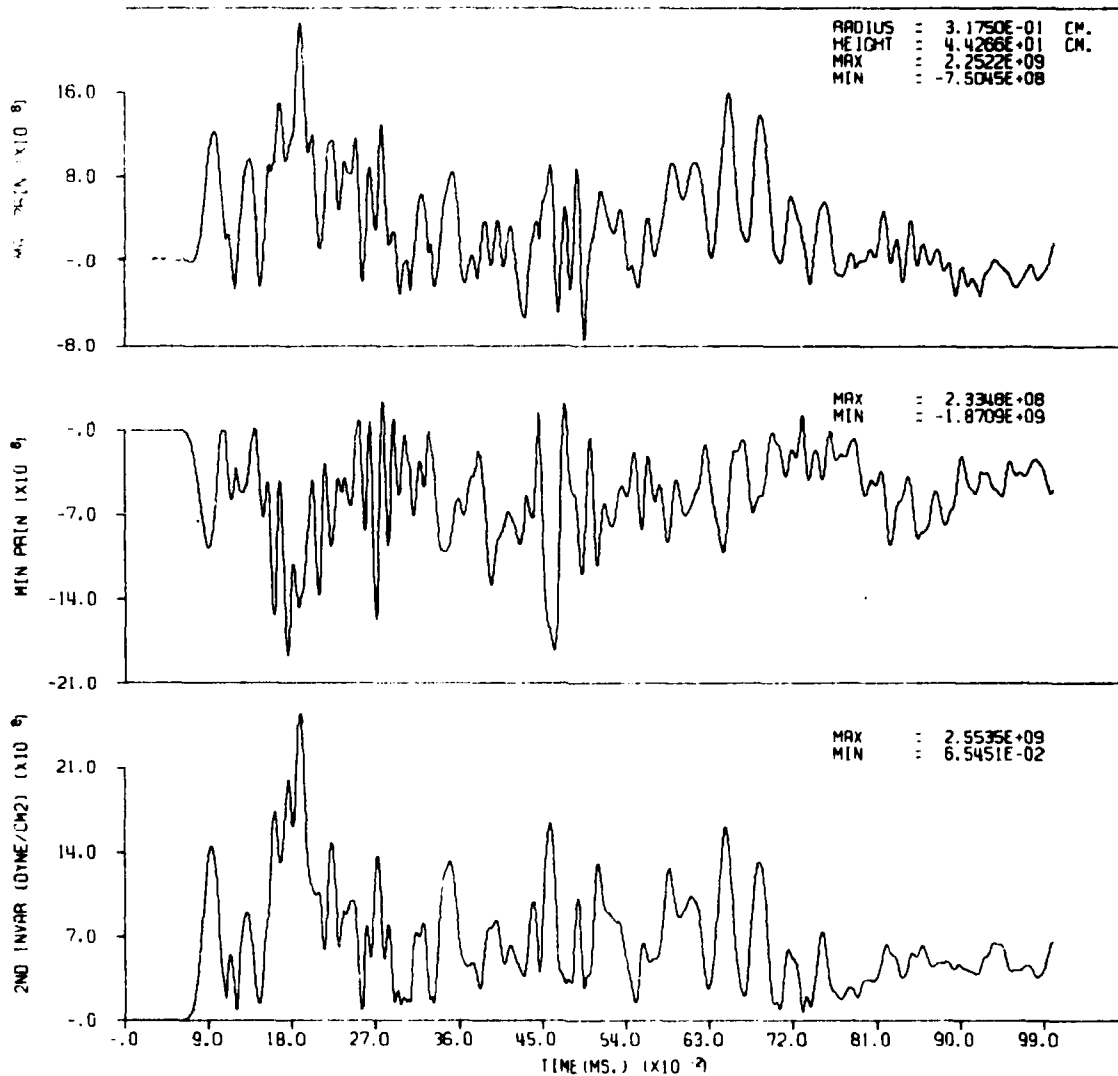
STATION

6

PLOT PREPARED BY ADJ. ADJ.

FIGURE II-10

STRESS TENSOR CHARACTERISTICS



TOODY 21.3 CADM WITH AFX108 FILL. COMPLETE STRESS TENSOR.

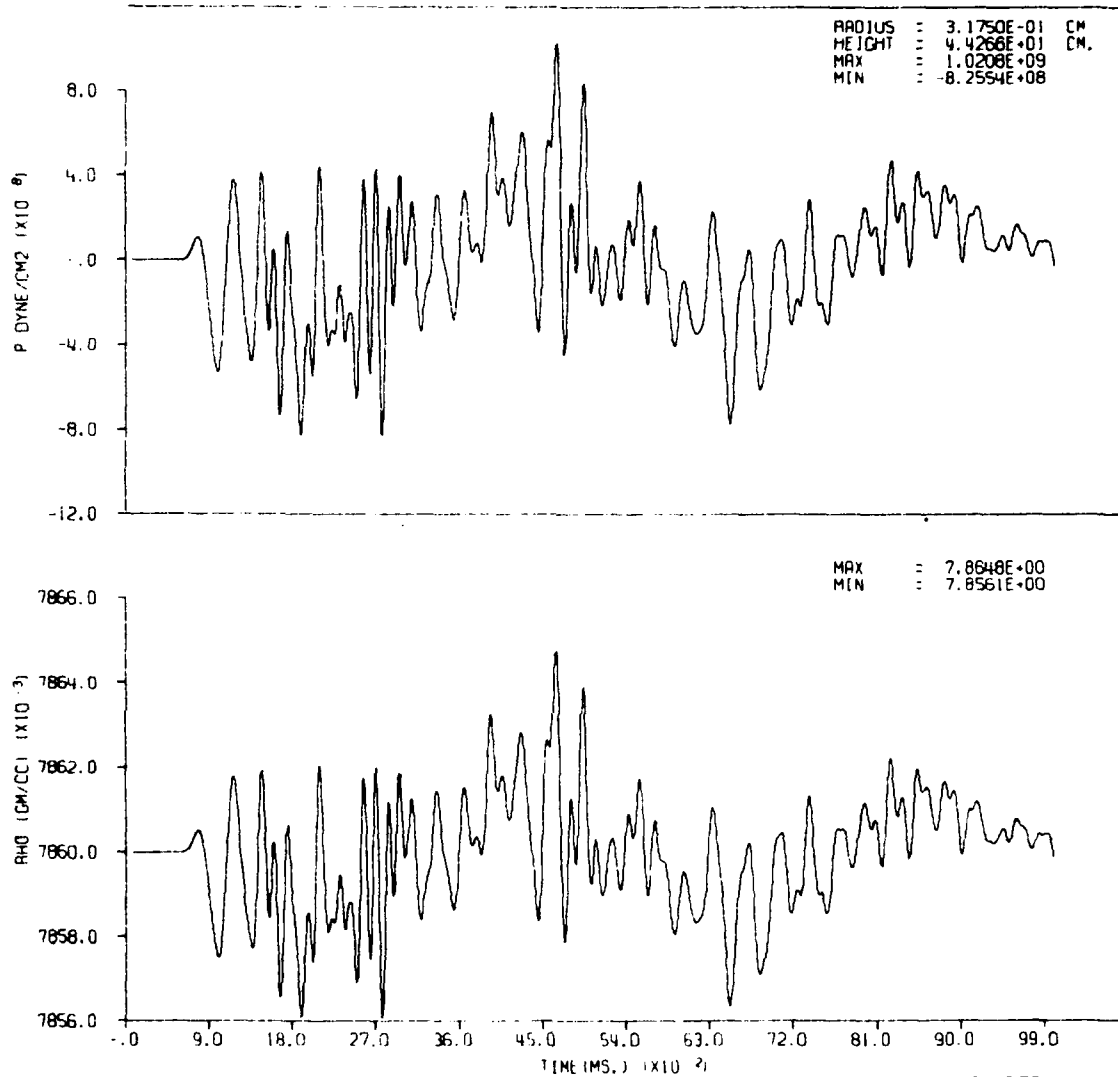
PROBLEM 0.0000

STATION 6

PLOT PREPARED BY AD, ADIC

FIGURE II - 11

DENSITY AND PRESSURE



TODDY 21.3 CROM WITH AF X108 FILI. COMPLETE STRESS TENSOR.
 PROBLEM 0.0001 STATION 6
 PLOT PREPARED BY AD. ADIC

FIGURE II - 12

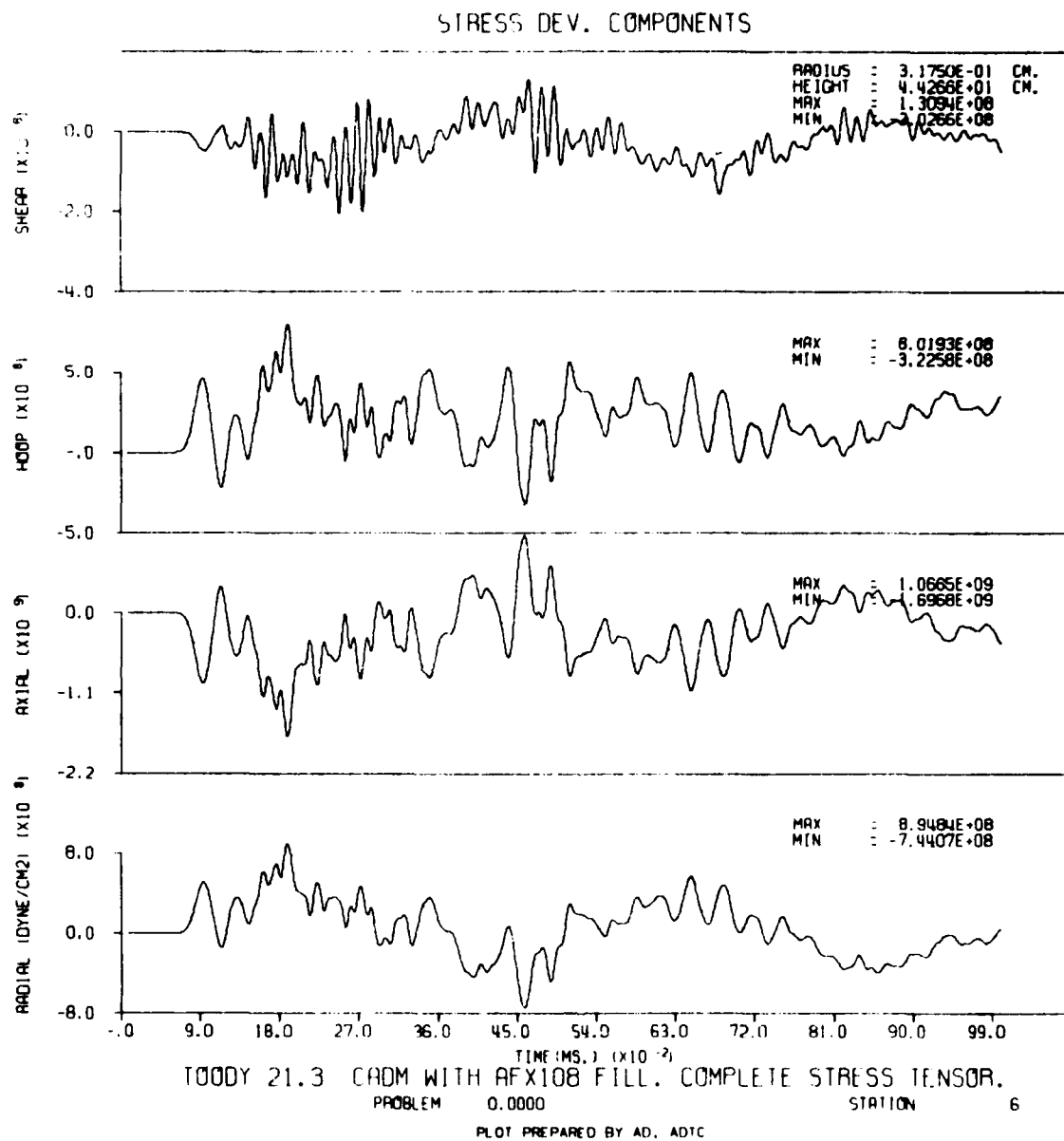
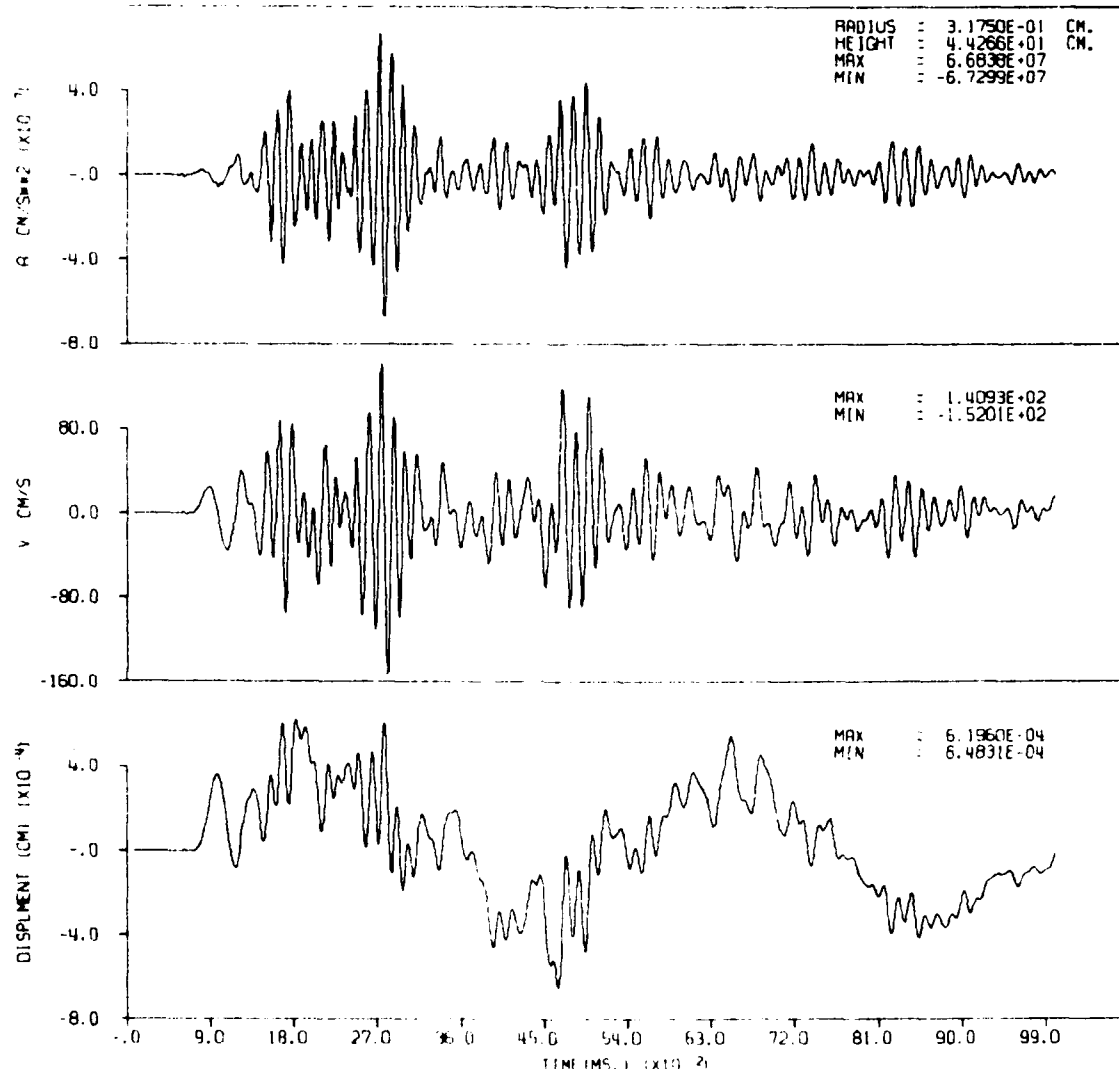


FIGURE II - 13

RADIAL MATERIAL MOTION



TOODY 21.3 CADM WITH AX108 FILL. COMPLETE STRESS TENSOR.
 PROBLEM 0 0000 STATION 6
 PLOT PREPARED BY ADL ADTC

FIGURE II - 14

AXIAL MATERIAL MOTION

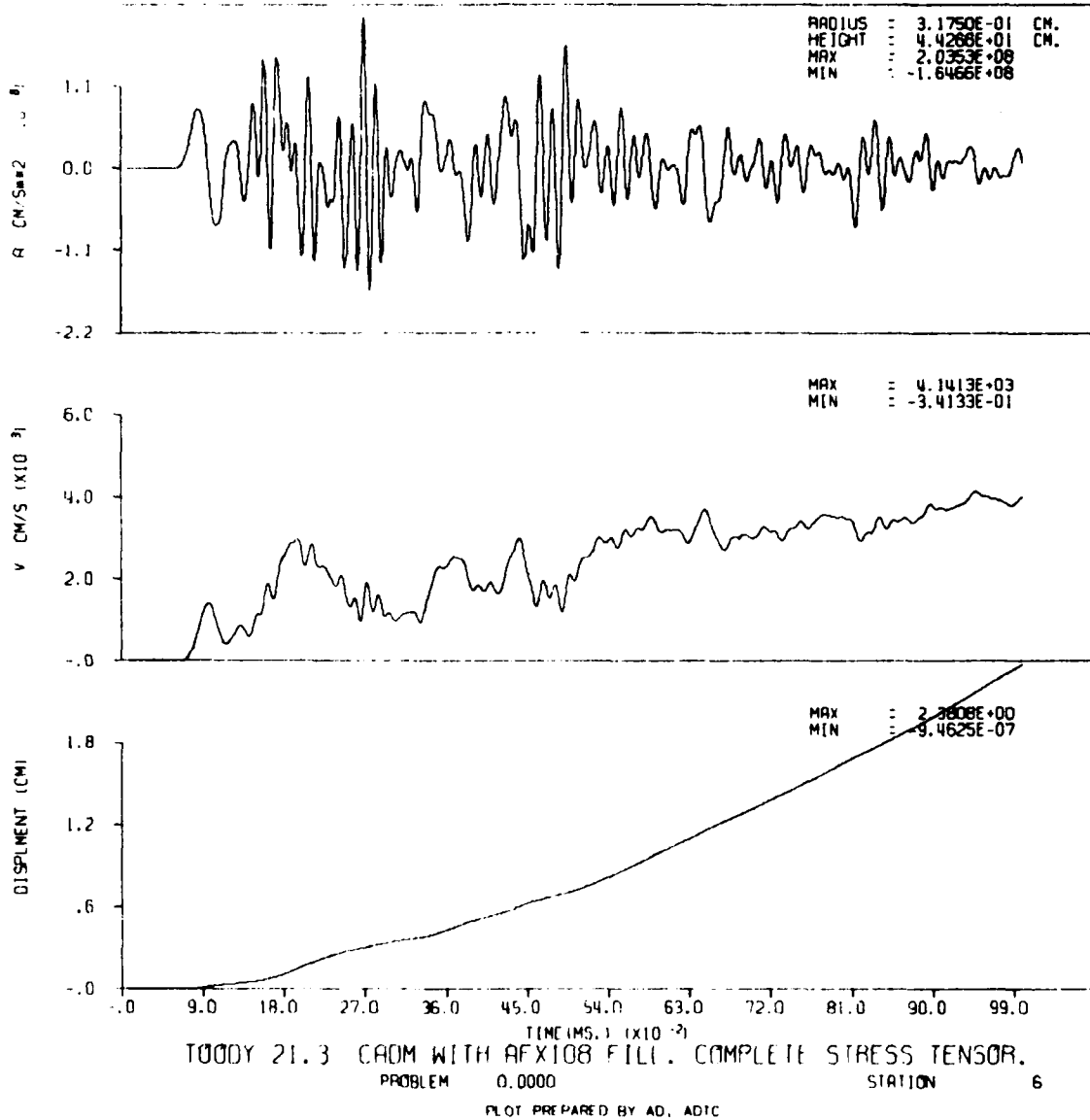


FIGURE II - 15

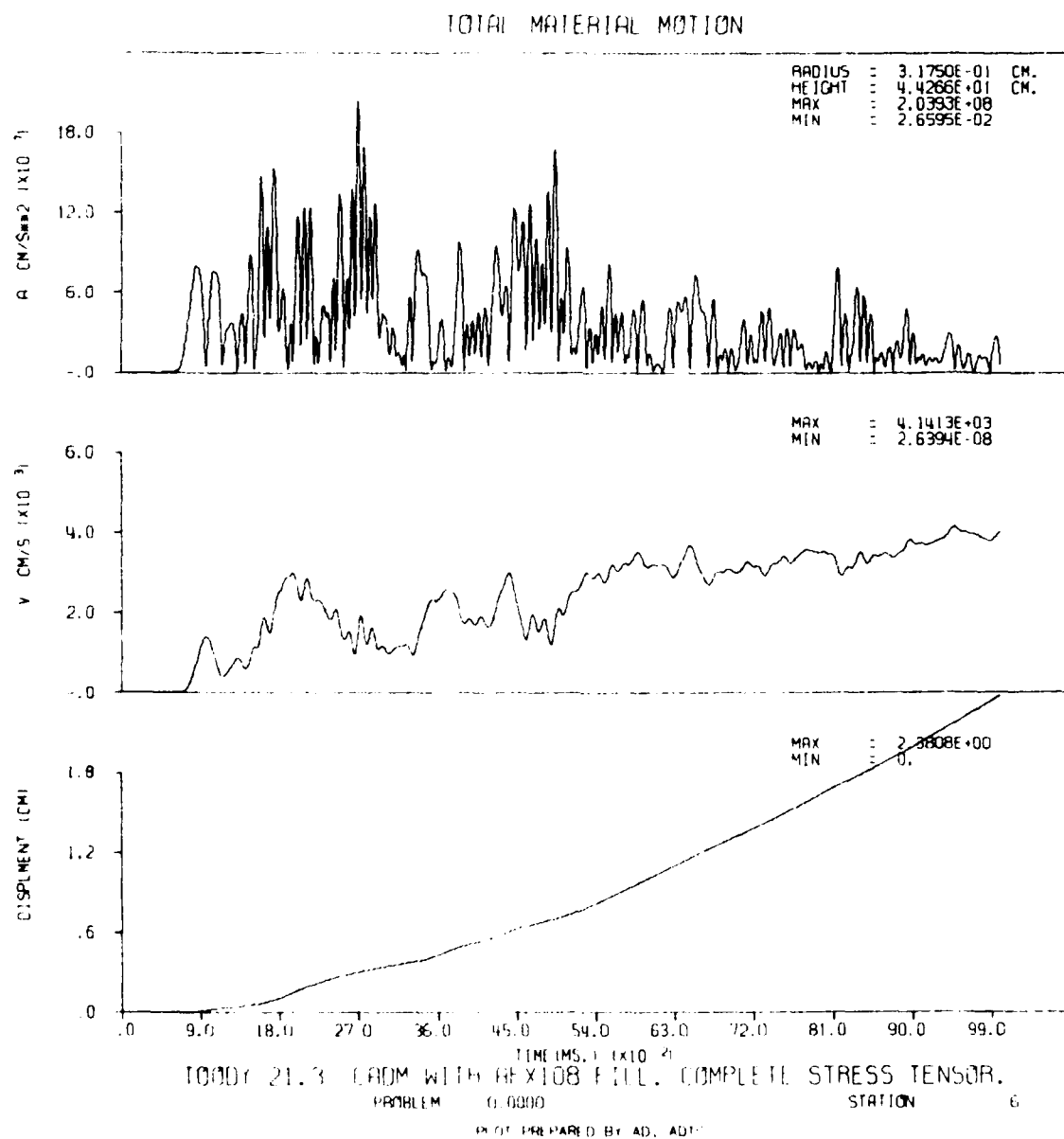


FIGURE II - 16

between COMMON blocks. To dump the entire code change ISHORT to 0.

Utility routines have been written to allow zone dropping as specified by the user. These routines are often essential to continued running in very violent problems. The alternative is to use rezoning. Fortunately many problems become highly distorted in areas of little interest and at a time such that they can be dropped out of the grid without adverse effects. Of course, such drops have to be carefully studied or they can actually change the problem away from that desired.

Input to use zone dropping routines has to be UPDATED into SUBROUTINE DROPIN (use *I DROPIT.19 followed by the appropriate information). The input information needed for each drop is TTDROP(K), IIDROP(K), JJDROP(K) and JTIDROP(K) where K can vary from 1 to 20 (that is, up to 20 drops can occur). TTDROP is the time of the drop in seconds. If it is desired to drop II columns then JJDROP and JTIDROP must be 0 and IIDROP set to the number of II columns to drop. Dropping begins with column 1 and goes through IIDROP. Each column is entirely dropped from the problem and arrays such as IGRDMIN and IGRDMAX, IITIME, etc. are adjusted. Coding assumes that IACT is up to IT-1 before any drops occur. Material indicators in the new II = 1 column are changed to 21 (free) if the material in zone II+1 at the same JJ value is real (less than 20). The indicator is changed to that for II+1 at the same JJ value if the material indicator at (II+1, JJ) is a boundary indicator. It is assumed that no more than one section of II lines will be deleted on any one drop.

If it is desired to drop JJ rows, then IIDROP is set to zero and JJDROP is set to the last real JJ value it is desired to retain. The drop can occur in only one section. That section is specified by setting JTIDROP. For example, if it is desired to drop JJ = 26 through 30 (where 30 is JMAX in the JTIDROP section) then set JJDROP to 25. JMAX of the new section so created will be 26. Real material will therefore end at JJ = 25. It is always assumed that the drop goes through JMAX (JTIDROP). Arrays such as JGRDMIN, JGRDMAX, JJTIME, etc. are automatically updated to reflect the change. The boundary indicator at the new JMAX is set to that at the old JMAX.

If IACT = IT-1 prior to any drops then there will be no conflicts if the problem has to be restarted. However, the restart deck should have new values for IT, JT, GRID and GRAPH indices and section definition (the card beginning with NJVAR). Material indicator cards and geometry definition cards need not be changed from their old values. The history station indices can also remain at their old values.

Subroutine DFPRINT places a message in the dayfile whenever a restart file is made, the problem terminates or SWITCH 2 is ON. The message gives IACT, NCYCLE, T and DT values plus NFILE (the restart file being made).

PPCALL is a local ADTC system routine. As used in TOODY it returns the job card time limit so that TOODY can exit gracefully (i.e. by ending files, doing plotting chores, etc.) prior to CP time limit.

CODE TERMINATION-AIR FORCE AND SANDIA

TOODY will terminate if T is greater than or equal to TMAX, SWITCH 1 is ON, job card time limit is only 30 seconds away or if CP time exceeds RSMAX. At termination, a restart file is made if RSMIN is non-negative, GRID and GRAPH plotting are accomplished if called for by input, printing is accomplished if called for by input and time station buffer areas are dumped on TAPE 12.

INTERMEDIATE VARIABLE STORAGE-AIR FORCE

Intermediate variables are stored only on disc (TAPE 21 and TAPE 22). Some versions of TOODY use Extended Core Storage (ECS). Since the AFATL has no ECS, this version of TOODY relies completely on disc. It would be fairly simple to modify the code to use ECS. BUFFER IN and OUT statements could be changed to READDEC and WRITEDEC statements. All IF UNIT checks on NTP1 and NTP2 would have to be deleted.

As now written, the AFATL TOODY uses overlapping buffering and numerical computing - i.e., a buffer operation is started and the code does not wait for it to be finished (an IF UNIT check) until the data is absolutely required for further computing.

BOWTIE DISTORTION CORRECTION-SANDIA

TOODY has a built in viscosity term to dampen hourglass or bowtie zone distortions. The viscosity is controlled by IKEYSW (1 for on, 0 for off) and XKCON (the amount of viscosity). IKEYSW is set to 1 and XKCON to 0.25 automatically. XKCON (set in SETUP) should never exceed 1. (XKCON is multiplied by 0.1 in MAIN prior to use).

DEBONDING/REBONDING SLIDE LINE-SANDIA

A slide line option has been added by Sandia to allow slide lines to collide, debond and rebond. The material indicator for this type of line is MAT=26. Collision and separation must proceed only from points bounding the area in contact. Separation proceeds one left hand mesh per cycle. Collision proceeds until the first non-collision is found. Additional input is required to use this option. The arrays JMINL, JMAXL, JMINR and JMAXR must be input for each interface. In addition, separation stresses must be input in the array SIGSEP. JMINL and JMAXL define the JJ values away from the region of contact for the left side of the slide line. JMINR and JMAXR provide the same definition for the right side. Debonding occurs when normal stress across the slide line exceeds the SIGSEP value for that line.

MOMENTUM CALCULATION-SANDIA

Sandia has added a more accurate momentum zone calculation than specified in References 1 and 2. It no longer assumes that the areas and masses of the momentum zone are one fourth of the totals for the four zones. Instead it computes the area and mass each time they are required. This improves the accuracy of the momentum calculation for non-rectangular zoning or rectangular zoning which has been distorted.

JACT-AIR FORCE

John Levesque, while at AFWL, added coding for an activity counter along JJ rows. The activity counter is controlled by the input variable JACT. Each II column has its own activity counter, JKACT(II).

Initially, all JKACT values are set to JACT. After that they each advance by comparing pressure at JKACT(II)+1 to PACT. Computations are made along each II column through JKACT(II)+1. Zone variables from JKACT(II)+2 through JT are kept at their old values. This option has not been thoroughly checked in AFATL TOODY. There may be some problem in using it with other features. Presently, JACT is always set to 0, bypassing the option. If the user desires to calculate with JACT he can UPDATE a non-zero value into SETUP.

PRINT EDITS-AIR FORCE

Printing is controlled by IPRINT as in References 1 and 2.

In addition, the code now prints out the weight of each material in grams and pounds at SETUP time. TOODY uses one radian of arc around an axis of rotation. The weight printout, however, multiplies by 2π so that the complete weight of the object being modelled is given. It also prints out mass averaged velocity components every time GRIDS is called.

UNITS-AIR FORCE

It is highly recommended that only CGS units be used as inputs. These are:

Dimensions	cm
Stress	dynes/cm ²
Energy Density	ergs/gm
Mass	gm

There are some routines in TOODY, such as the initial weight computations, which assume CGS is used.

INPUT CARD FORMAT-AIR FORCE

Input is now format free and uses the READ * option in FTN. Under this option input can be in any fields on the card. Input variables are separated by blanks or commas. Floating point variables can be input as integers, numbers with a decimal point or in E format. For example, the number 100 can be input as 100, 100. or 1.E2. Integers must not be E type or have decimal points in their field.

All numbers to be read by a READ * command must be on the card. Blank fields are not understood since blanks are delimiters.

PREPROCESSOR-SANDIA AND AIR FORCE

Sandia added a preprocessor program to read TOODY input and size some arrays, particularly the IC array. This preprocessor has been extended by the Air Force and deletes unnecessary equations of state, sliding routines if there are no slip surfaces in the problem, etc., in addition to sizing many arrays. The preprocessor makes a file named DCJID which contains UPDATE commands. TOODY uses this file through a *READ DCJID card in the TOODY UPDATE deck. This system insures that TOODY is no larger than required for any given problem.

SECTION III

INPUT

AFATL TOODY input is discussed below. Unless specified, input is format free.

CARD 1 (A10 Format)

Problem ID line - blank if a restart

CARD 2

IT, JT, NOMAT, IALPH, IGRID, IGRAF, IPRINT, ISPEC, IACT

where

IT is the max II value in the problem

JT is the max JJ value if sections are not used. JT = 0
if sections are used.

NOMAT is the number of real materials

IALPH is the symmetry indicator.

0 if the X axis is an axis of rotation

1 if plane geometry

2 if the Z axis is an axis of rotation

IGRID is the number of GRID type plots

IGRAF is the number of GRAPH plots

IPRINT is 1 for print output, 0 otherwise.

ISPEC is the number of time history stations

IACT is the initial value of the II activity counter.

If IACT = 0, it is set to IT-1. It is advanced by
comparing pressure in the zones along IACT+1 with PACT.

PACT is set automatically to 100 dynes/cm².

CARD 2

TMAX, IHULLIN, RHOFF, YHOFF

where

TMAX is max problem time in seconds.

IHULLIN is 1 if HULL input is to be used.

RHOFF, YHOFF are radial and axial offsets to be added to HULL station coordinates.

NOTE: There are many variables which would be input at this time in the code specified by References 1 and 2, but which are now set automatically. To change these values one would have to UPDATE in new values in SETUP. These are

PMAX = 50.E12 (max pressure allowed)

XKX = 0.8 (time step multiplier)

B1 = 1.2 (bulk quadratic viscosity coefficient)

B2 = 0.6 (bulk linear viscosity coefficient)

B3 = B4 = 0 (deviator viscosity coefficients)

DELTMIN = 1.E-12 (min time step allowed)

DELT = 1.E6 (code then will choose initial time step)

DDT = 1.1 (time step max growth factor)

IECSW = 0 (energy check switch)

IRRSSW = 0 if ID line not blank

= 1 if ID line blank

IRSF = 1 (restart file number)

IGNORDT = 0

JACT = 0 (this bypasses all JJ activity checks)

CARD 3 (Present only if IPRINT = 1

TPDEL, IPMIN, IPMAX, IPDEL, JPMIN, JPMAX, JPDEL

where

TPDEL is the increment in problem time at which print edits
are desired.

Edits are desired for II values, IPMIN, IPMIN + IPDEL, ..., IPMAX
and JJ values JPMIN, JPMIN + JPDEL, ..., JPMAX

CARD 4 (present only if ISPEC greater than 0

NOTE: There are ISPEC numbers of Card 4. Each card applies to a
single station.

IITIME, JJTIME, XTIME, ZTIME

where

IITIME, JJTIME is the II, JJ for the time history station.

XTIME, ZTIME is the X,Z, for the station.

Either II, JJ or X, Z can be specified with zero values for the other
unspecified set.

CARD 5 (present only if IGRID greater than 0)

TGRDDEL

where

TGRDDEL is the problem time increment at which GRID plots
are desired.

CARDS 6 and 7 (present if IGRID greater than 0)

NOTE: There are IGRID sets of Cards 6 and 7

IGRDMIN, IGRDMAX, JGRDMIN, JGRDMAX, IOPTION
XGRDMIN, XGRDMAX, ZGRDMIN, ZGRDMAX, XHORIZ

When

IGRDMIN is the minimum II value for the plot

IGRDMAX is the maximum II value for the plot

JGRDMIN is the minimum JJ value for the plot

JGRDMAX is the maximum JJ value for the plot

IOPTION is 0 for grid plot

1 for velocity vector plot

2 for a plot showing zones which have ever been plastic

3 for a plot showing zones which have ever had a
pressure less than PMIN

XGRDMIN, XGRDMAX are min and max values of X desired on the plot

ZGRDMIN, ZGRDMAX are min and max values of Z desired on the plot

XHORIZ is 0 if the X axis should be horizontal on the plot.

It is 1 if the Z axis should be horizontal.

CARD 8 (present only if IGRAF greater than 0)

TGRFMIN, TGRFDEL

where

TGRFMIN is the first problem time at which GRAPH plots are desired.

TGRFDEL is the problem time increment for plots.

CARDS 9 and 10 (present if IGRAF greater than 0)

There are IGRAF sets of cards 9 and 10 required.

IGRFMIN, IGRFMAX, IGRFDEL JGRFMIN, JGRFMAX

OGMIN, OGMAX, IORDGF

where

IGRFMIN is min II for the plot

IGRFMAX is max II for the plot

IGRFDEL is the increment in II

JGRFMIN is min JJ for the plot

JGRFMAX is max JJ for the plot

OGMIN is min value for the ordinate

OGMAX is max value for the ordinate

If OGMIN=OGMAX=0 then the code assigns min and max values

IORDGF indicates which zone variable to plot vs X. The possible input values are

<u>IORDGF</u>	<u>VARIABLE</u>
4	X
5	Z
6	UX
7	UZ
8	TXX
9	TTY
10	TZZ
11	TXZ
12	Q
13	EXX (really DQXX)
14	EZZ (really DQZZ)
15	EXZ (really DQXZ)
16	RHO
17	C
18	E
19	AL
20	XM
21	BT
22	BT1
23	BT2
24	EYY(really BT3)
25	Total Velocity
26	Pressure

CARD 11 (present only if IECSW has been UPDATED to a value of 1)

EPE, ECON, NSCYCLE

where

EPE is the relative energy error allowed.

ECON is the value of energy below which no check will be made.

NSCYCLE is the cycle to begin checking

NOTE: Use of this energy check option is usually not required. If instabilities occur, they usually grow very rapidly resulting in violation of the PMAX criterion within a few cycles. There are other difficulties with using an energy check such as the fact that applied pressure work is not considered.

CARD 12

RSMIN, RSMAX, RSDEL

where

RSMIN is any negative number such as -1 if restart files
are not desired

is problem time for first dump if RSMAX is less than 0

is CP running time for first dump if RSMAX greater than 0

RSMAX is running time in CP minutes. Use a negative value if
restart dumps are desired at certain problem times.

In this case the absolute value of RSMAX is used for CP
time limit.

RSDEL is the increment in problem time at which restart dumps
are desired if RSMAX is less than 0.

is the increment in CP time (minutes) if RSMAX is greater
than 0.

Some examples are

-1, 30, 0 would mean no restart dumps desired and a max CP running time of 30 minutes. (in this case RSDEL has no meaning and can be set to 0)

10.E-6, -30, 20.E-6 would mean dumps are desired every 20.E-6 seconds problem time beginning at 10.E-6 seconds and that 30 minutes is the CP time limit desired.

10, 120, 20 would mean dumps are desired after every elapsed 20 minutes CP time beginning at 10 minutes. The problem should run no more than 120 minutes.

CARD 13 (present only if JT = 0 on Card 2)

NJVAR, IJ(1), JMIN(1), JMAX(1), ..., IJ(NJVAR), JMIN(NJVAR),
JMAX(NJVAR)

where

NJVAR is the number of sections in the problem

IJ(1) is the last II value in the first section

JMIN(1) is the min JJ value in the first section

JMAX (1) is the max JJ value in the first section

.

.

.

IJ(NJVAR) is the last II value in the last section (IT)

JMIN(NJVAR) is the min JJ value for the last section

JMAX(NJVAR) is the max JJ value for the last section

NOTES: Up to 10 sections are allowed.

It is generally better to set JMIN values to 1 if at all possible.

CARD 14 (there can be up to 40 of the following material definition cards)

KM, IS1, IS2, JS1, JS2

where

KM is material number, including boundary indicators

IS1 is the starting II value for KM

IS2 is the ending II value for KM

JS1 is the starting JJ value for KM

JS2 is the ending JJ value for KM

CARD 15 (Material definition termination card)

This card terminates read in of material definition input. It must be one of the following. Either

0 0 0 0 0

or

0 -1 0 0 0

The latter is used if geometry definition cards are to be input later. The former is used if material definition cards also determine geometry definition.

CARD 16 (present if KM = 25 or 26 or any material definition cards)

FRICT(1), FRICT(2), ..., FRICT(ISLIDE)

where

FRICT(1) is the Coulomb friction coefficient for slide line1
(i.e., the slide line with the smallest II value)

FRICT(2) is the coefficient for the second slide line.

.
.
.

FRICT (ISLIDE) is the coefficient for the last slide line in
the problem.

NOTES: There can be no more than 8 slide lines.

FRICT = -1 means infinite friction (no sliding)

= 0 means perfect no friction, sliding

> 0 means slide with the friction coefficient specified.

CARD 16A (present if KM = 26 on any material definition cards)

JMINL(1)

JMAXL(1)

JMINR(1)

JMAXR(1)

.
.
.

JMINL(8)

JMAXL(8)

JMINR(8)

JMAXR(8)

CARD 16B (present if KM = 26 on any material definition cards)

SIGSEP(1)

SIGSEP(2)

.
.
.

SIGSEP(8)

CARD 17 (present only if the terminating material indicator card was

0, -1, 0, 0, 0)

KG, ISG1, ISG2, JSG1, JSG2

where

KG is geometry region number (beginning with 1).

ISG1 is min II value for region KG

ISG2 is max II value for region KG

JSG1 is min JJ value for region KG

JSG2 is max JJ value for region KG

CARD 18 (Geometry termination card. Present only if CARDS 17 present)

This card must be five zeros.

0 0 0 0 0

The next set of cards define equation of state properties for materials 1 through NOMAT. There are varying numbers of cards depending on the equation of state option. There must be NOMAT sets of these cards.

CARD 19

IES

where

IES is equation of state indicator

1 for state 1 (elastic/plastic)

2 for state 2 (high explosive)

3 for state 3 (ideal gas)

4 for state 4 (earth media)

(5 is not used)

6 for state 6 (metal foam)

7 for state 7 (GRAY metal)

9 for state 9 (slurry EOS)

Cards 19A, 19B, etc., vary depending on the state option.

IF IES = 1, then input

CARD 19A

po, co, PMIN, v

where

po is initial density

co is initial bulk sound speed

PMIN is min pressure allowed

v is Poisson's ratio

NOTE: $co^2 = \frac{(1 + v)}{3(1 - v)} c_{oL}^2$

where c_{oL} is initial longitudinal wave speed

CARD 19B

S, Γ_0 , NOY, Y0

where

S is the slope of the US/UP Hugoniot, If S = 0,

PH calculated as $\rho_0 co^2 \mu$

Γ_0 is initial Gruneisen ratio

NOY is strength indicator

- 0 - no strength
- 1 - elastic/perfectly plastic
- 2 - perfectly elastic
- 3 - energy variable plastic
- 4 - linear work hardening
- 5 - nonlinear work hardening

Y0 is initial plastic flow stress

CARD 19C (present only if NOY = 4)

Y1, Y2

where

Y1 is Young's modulus

Y2 is the tangent modulus

NOTES: This input has been greatly simplified from Reference 1 by making certain assumptions. These are

1. Rigidity modulus, G , is always

$$G = \frac{3(1 - 2\nu)}{2(1 + \nu)} K$$

where K is current bulk modulus.

2. Gruneisen ratio, Γ is always

$$\Gamma = \Gamma_0 \rho_0 / \rho$$

3. PH is either

$$PH = \rho_0 c_p^2 \eta / (1 - S_\eta)^2$$

or

$$PH = \rho_0 c_0^2 \mu$$

4. TDEP always -1 (no energy deposition)
5. EM always 1.E100 (no melt energy changes on PMIN or Y)
6. ESUB always 1.E100 (no switch to a vapor equation of state at high energys)

If these built-in defaults are not desired, the READ cards can be changed in SETUP or changes in equation of state values can be UPDATED into the code. If changes are desired, they should be made in the ESC array for the material. This array is as follows for material K

ESC (K, 1) = ρ_0

ESC (K, 2) = c_0

ESC (K, 3) = QDEP (energy/unit mass to deposit)

ESC (K, 4) = PMIN

ESC (K, 5) = TDEP (energy deposition time)

ESC (K, 6) = ν

ESC (K, 7) not used

ESC (K, 8) = NOK

if NOK = 0 then $PH = \rho_0 c_0^2 \eta / (1 - S_\eta)^2$

if NOK between 1 and 6, then

$PH = \rho_0 c_0^2 \eta (1 + k_1 \eta + k_2 \eta^2 + \dots + K_{NOK} \eta^{NOK})$

if NOK = 7, then

$PH = \rho_0 c_0^2 \mu (1 + K_1 \mu + K_2 \mu^2 + \dots)$

ESC (K, 9) = $\rho_0 c_0^2$ (filled in by the code)

ESC (K, 10) = S if NOK = 0

= K_1 if $NOK \geq 1$

ESC (K, 11) = K_2

.

ESC (K, 14) = K_4

ESC (K, 15) = NOH

if NOH = 0, $\Gamma = \Gamma_0$

if NOH ≥ 1 ,

$\Gamma = \Gamma_0 (1 + H_1 \eta + H_2 \eta^2 + \dots + H_{NOH} \eta^{NOH})$

$$\text{ESC}(K, 16) = \Gamma_0$$

$$\text{ESC}(K, 17) = H_1$$

·
·
·

$$\text{ESC}(K, 21) = H_5$$

$$\text{ESC}(K, 22) = \text{NOG}$$

$$\text{NOG} = 0 \text{ if } G = \frac{3(1 - 2\nu)}{2(1 + \nu)} K$$

$$\text{NOG} \geq 1 \text{ if}$$

$$G = G_0(1 + g_1 \eta_1 + g_2 \eta_1^2 + \dots)$$

$$\eta_1 = 1 - \frac{\rho_0}{1/2(\rho^{n+1} + \rho^n)}$$

n = cycle number (not an exponent)

$$\text{ESC}(K, 23) = G_0 \text{ (filled in by the code)}$$

$$\text{as } \frac{3(1 - 2\nu)}{2(1 + \nu)} \rho_0 \rho_0^2$$

$$\text{ESC}(K, 24) = g_1$$

·
·
·

$$\text{ESC}(K, 28) = g_5$$

$$\text{ESC}(K, 29) = \text{NOY}$$

$$\text{ESC}(K, 30) = Y_0$$

$$\text{ESC}(K, 31) = Y_1$$

ESC (K, 32) = Y2

ESC (K, 33) = Y3 (used only for NOY = 5)

ESC (K, 34) = EMELT

ESC (K, 35) = ESUB

ESC (K, 36) = $\gamma-1$ for vapor equation

If EMELT, energy density at melt, is specified then Y and PMIN are multiplied by

$$1 - E/EMELT$$

prior to use.

ESUB is the vaporization energy density and is used in the vapor equation with $\gamma-1$ (See Reference 1)

If IES = 2, then Input

CARD 19A

po, D, D, γ , ϕ , 0, 0, 0 if gamma-law explosive desired.

D is detonation velocity. Energy of detonation is computed internally as $D^2/(2(\gamma^2 - 1))$

po, D, E, A, B, R1, R2, W if JWL explosive desired.

CARD 19B

ND, XD, ZD, TOBURN, KO

ND is detonation option

ND = 1 ignite from line Z = ZD

ND = 2 ignite from line X = XD

ND = 3 ignite from point (XD, ZD)

ND = 4 ignite all explosive at the same time.

TOBURN Time for explosive to begin igniting (normally 0)
 KO Bulk modulus for unignited explosive. If non-zero
 pressure computed from $P = K_0 \mu$
 If $K_0 = 0$, pressure computed from
 $P = \rho_0 c_0^2 \eta / (1 - s \eta)^2$
 where ρ_0 , c_0 and S are appropriate for composition B.
 If IES = 3, then Input

CARD 19A

ρ_0 , c_0 , γ , 0, 0, 0, 0, 0
If IES = 4, then Input

CARD 19A

ρ_0 , C_p , $PMIN$, v , $PELAS$, $PLOCK$, $\mu LOCK$

where

ρ_0 = initial density
 C_p = initial longitudinal wave velocity
 $PMIN$ = minimum pressure allowed
 $PELAS$ = max pressure prior to crushing
 $PLOCK$, $\mu LOCK$ = define intersection of crush curve with lockup
 curve

CARD 19B

C_{0L} , S , Y_0 , YV , PV , $GMAX$, $PMID$, μMID

where

C_{0L} and S define the lock-up Hugoniot, $U_S = C_{0L} + S U_p$

Y0, YV, PV define the yield surface

GMAX is limiting rigidity modulus (input 0 if no limit desired)

PMID, μ MID = defines crushup curve between PELAS, μ ELAS and PLOCK,

μ LOCK

NOTES:

1. To run as a fluid medium input $\nu = 0.5$, $Y0 = YV = PV = 0$
2. To use the built-in concrete equation of state, the first card, CARD 19A, should be all 0's. In this case, CARD 19B is not required.

If IES = 6, then Input

CARD 19A

ρ_0 C_0 , QDEP, PMIN, TDEP, B5, B6

where

ρ_0 = initial density of the solid

C_0 = initial bulk sound speed of solid

QDEP = energy density to be deposited

PMIN = minimum pressure

TDEP = energy deposition time (-1 if no deposition)

B5, B6 are extra viscosity terms.

B5 = 3, B6 = 0.7 are good values

CARD 19B

NOK, 0, K or S, K2, K3, K4, K5

Hugoniot definition for the solid

CARD 19C

NOH, Γ_0 , H1, H2, H3, H4, H5

Gruneisen ratio definition

CARD 19D

C_e , α_0 , P_{e0} , P_{s0} , K, E_0 , 0

where

C_e = initial foam sound speed

α_0 = initial distention ratio

P_{e0} = elastic limit pressure for unheated material

P_{s0} = pressure at which all voids are filled for unheated material

K = coefficient in energy dependence equations for P_{s0} and P_{e0} .

Set to -2 if it is input as a 0.

E_0 = energy at which foam strength becomes negligible. Set to

0 for energy independent model.

CARD 19E

ESUB, $\gamma-1$, 0, 0, 0, 0, 0, 0

Terms for vapor equation

If IES = 7, then Input

CARD 19A

ρ_0 , C_0 , QDEP, PMIN, TDEP, ν , 0

where TDEP = -1 for no energy deposition

CARD 19B

S, γ_0 , a, GE, TMO, AW, RJ

CARD 19C

RB, AY, TH, TRFLAG, 0, 0, 0

CARD 19D

NOG, 0, g_1 , g_2 , g_3 , g_4 , g_5

CARD 19E

NOY, Y0, Y1, Y2, Y3, 0, 0, 0

The ESC array for State 7 is as follows:

ESC (K, 1) = ρ_0

ESC (K, 2) = C_0

ESC (K, 3) = QDEP

ESC (K, 4) = PMIN

ESC (K, 5) = TDEP

ESC (K, 6) = ν

ESC (K, 7) = Not Used

ESC (K, 8) = S

ESC (K, 9) = γ_0

ESC (K, 10) = α

ESC (K, 11) = GE

ESC (K, 12) = TMO

ESC (K, 13) = AW

ESC (K, 14) = RJ

ESC (K, 15) = RB

ESC (K, 16) = AY

ESC (K, 17) = TH

ESC (K, 18) = TRFLAG
ESC (K, 19) = Not Used
ESC (K, 20) = Not Used
ESC (K, 21) = Not Used
ESC (K, 22) = NOG
ESC (K, 23) = GO (Code fills in)
ESC (K, 24) = g_1
ESC (K, 25) = g_2
ESC (K, 26) = g_3
ESC (K, 27) = g_4
ESC (K, 28) = g_5
ESC (K, 29) = NOY
ESC (K, 30) = Y0
ESC (K, 31) = Y1
ESC (K, 32) = Y2
ESC (K, 33) = Y3
ESC (K, 34) = Not Used
ESC (K, 35) = Not Used
ESC (K, 36) = Not Used

If IES = 9, then Input

CARD 19A

po, D, E, A1, B1, R11, R21, W1

where D is detonation velocity, E is energy per unit mass released upon initial burn, A1 through W1 are parameters for the first JWL EOS.

CARD 19B

TRAMP, EZDEL, A2, B2, R21, R22, W2

Where TRAMP is the time required to release the delayed energy EZDEL and A2 through W2 are parameters defining the second JWL equation.

CARD 19C

ND, XD, ZD, TOBURN, B5

where ND, XD, ZD and TOBURN have the same meaning as in State 2. B5 is a control on time required to completely burn a zone. It should be input as 2.5.

CARDS 20, 20A and 20B are required to define shape definition for each geometry region. The cards are arranged in order for geometry regions 1 through NGEOM (the last geometry region)

CARD 20

ISET

where ISET = shape option. This is an integer from 1 through 10. In addition, the following two cards are required.

CARD 20A

X0 XCON(1) XCON(2) XCON(3) XCON(4) JMIN JMAX

CARD 20B

Z0 ZCON(1) ZCON(2) ZCON(3) ZCON(4) IMIN IMAX

where IMIN, JMIN, IMAX and JMAX define the boundaries of the region.

NOTE: Velocities are no longer input but must be added using
UPDATE if non-zero values are required.

If ISET = 7 a third card is required as shown below.

CARD 20C

R12, R23, R34, R41, e_{XI} , e_{XJ}

The specific meaning of X0, XCON(1), etc., varies with shape option.
Section II of this report and Reference 1 explain these meanings.

SECTION IV

CONTROL CARDS

The control card setup for running under SCOPE 3.4 is as follows:

JOB CARD

CARDS NECESSARY TO BRING IN TDPREP and TDMAIN OLDPL files.

COPYCR, INPUT, TAPE 50.

REWIND, TAPE 50.

UPDATE, F, P = TDPREP, W.

FIN, A, I = COMPILE.

LGO.

REWIND, LGO.

UPDATE, F, P = TDMAIN, W.

FIN, A, I = COMPILE

CARDS NECESSARY TO ASSIGN ANY REAL TAPES TO TAPE 12,

TAPE 9, TAPE 25, TAPE 26 and/or TAPE 27

LGO.

7/8/9

TOODY INPUT DECK

7/8/9

* COMPILE PREPRS

ANY PREPROCESSOR UPDATE CARDS

7/8/9

* COMPILE TOODY 3

* READ DCJID

ANY TOODY MAIN UPDATE CARDS

6/7/8/9

It is assumed that TDPREP and TDMAIN are separate OLDPL files in a sequential (W) format.

SECTION V

SOME TIPS ON SUCCESSFUL RUNNING

A number of lessons have been learned by many users over the years. This section discusses some of the more important of these.

At least two zones are required across any material region. A single zone can cause numerical difficulties and return an incorrect answer. Two zones is the absolute minimum and can be used only in cases in which the material's mass is the dominant feature--as for example in bomb casing being driven off by explosives. Three to five zones are needed for any reasonable shock definition across the material.

Zone aspect ratios (length to width) should not exceed 5.

The peak pressure in an explosive zone will be a function of its size. Zones of size 0.1cm x 0.1cm are required to achieve 90% or so of the Chapman - Jouget pressure. On the other hand, peak pressure is often less important than impulse. In this case zones of 0.2 to 0.25cm widths and lengths are adequate.

The JWL explosive formulation should be used whenever possible. A constant gamma explosive will impart 20 to 30 percent too much impulse.

If there is too large a jump in the factor mc (mass times sound speed) across a material interface, the wrong answer can result.

Ideally, mc changes should be limited to no more than a factor of 5. A frictionless slide surface between materials decouples the momentum equation on both sides so that this mc rule can be violated at that location.

The accuracy of the momentum equation approximation deteriorates as zones become highly distorted. Such zones should be dropped if possible or rezoned to more regular shapes.

State 1 in TOODY was designed for stresses up to 500kb or so and temperatures up to one-half of the material's melt temperature. Changes in Y and PMIN with energy and the vapor equation of state are inaccurate in all but their most gross features. If material is expected to melt or vaporize better equations should be used. Such equations have been developed by Sandia (the ANEOS routines) and by Lawrence Livermore Laboratory (the GRAY routines) for several metals.

It is recommended that PMIN be set so low for metals that it is never reached -- e.g., at $-1.E13$ or so. PMIN is not really a good way to handle spall. If spall cannot be handled with a debonding slide surface, it cannot be handled correctly. Short of a slide surface, the best approach is to monitor principal stress and strain in a zone and decide if the zone has fractured based on considering both values. The momentum routine (starting with Statement 800 in MAIN) can then be changed to use zero stresses when the zone is fractured. In this way, neighboring zones will encounter a free

surface (zero stresses) and at least they will move correctly.

Such changes can be UPDATED into TOODY very easily.

To avoid negative areas a vector in the direction of increasing II crossed into a vector in the direction of increasing JJ must have the same sign as a unit vector in the Z direction crossed into a unit vector in the X direction. This results in most users automatically letting Z increase with II and X increase with JJ. The cross products then automatically have the same signs.

TOODY has no built-in provision for triangular zones. Triangular zones can be set up but will fail the time step calculations in SETUP 1 and MAIN and the momentum routine in MAIN. If triangular zones are to be used then these coding areas must be changed. The time step can be computed using $\text{SQRT}(\text{AL})$ instead of distance. The momentum calculation changes required depend on the problem. There is no general change which will work for all possibilities.

TOODY cannot be successfully run (on any but the simplest problems) by a casual user -- e.g., one who spends a day or two reading the documentation and then inputs his problem. The code has not been written by anyone which will allow this type of black box treatment. To consistently run this code, or any hydrocode, successfully requires patience and persistence and a willingness to dig into the detailed coding.

REFERENCES

1. "TOODY II, A Computer Program for Two-Dimensional Wave Propagation", Bertholf and Benzley, Sandia Report SC-RR-68-4, Nov 68.
2. "TOODY II-A, A Computer Program for Two-Dimensional Wave Propagation CDC 6600 Version", Bertholf and Benzley, Sandia Report SC-DR-69-516, Nov 69.
3. "Adiabatic Expansion of High Explosive Detonation Products", Lee, Horning, Kury, LLL Report UCRL-50422, 2 May 68.
4. "Compendium of Shock Wave Data", UCRL-50108 (Vol 1), M Vanthiel, June 66.
5. Allen, Mayfield and Morrison 1957, J. Appl. Phys. 28, pp 370-396.
6. "Gray, A Three-Phase Equation of State for Metals", Royce, UCRL-51121, Sep 71.

APPENDIX A
PLAIN CONCRETE CONSTITUTIVE RELATIONS
AT HIGH STRESS LEVELS

Calculations of projectile impacts or explosive detonations in concrete require a model for concrete constitutive relations at high stress levels. The purpose of this appendix is to present a model designed to simulate concrete response in the 1Kb to 300Kb stress region and be reasonably accurate in the lower stress regions. It is based on a very small amount of data. Most concrete testing has been conducted at stress levels below 10,000 PSI (less than 1 Kilobar). There is a great amount of research still needed to adequately answer many basic questions concerning concrete response at higher stress levels.

The model will be constructed primarily from Hugoniot data on one specific concrete⁽¹⁾ and static yield strength data on several concretes⁽²⁾. Assumptions will be made for a Poisson's ratio value, a shear modulus formula, a plastic flow rule and other parameters.

Gregson generated Hugoniot data to stress levels over 500 Kilobars for one specific concrete. He used a granite aggregate with an average particle diameter of 1/8 inch. The initial density varied from mix to mix, but averaged 2.185 gm/cc. The solid density had an average value of 2.673 gm/cc. The concrete consisted of 18% voids, 25% feldspar grains, 20 to 25% quartz

- (1) Gregson, "A Shock Wave Study of Fondu-Fyre WA-1 and a Concrete", DAA 2797F, Feb 72.
- (2) Chinn and Zimmerman, "Behavior of Plain Concrete Under Varying Compression Loading Conditions", AFWL TR 64-163, Aug 64.

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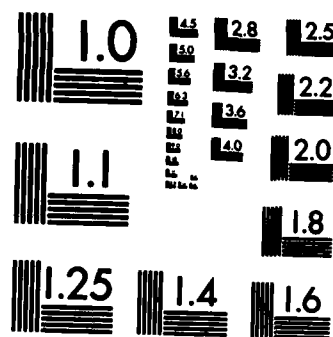
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MICROCOPY RESOLUTION TEST CHART
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grains and 25 to 30% cement paste by volume. The small aggregate size was dictated by his shock generating method, which consisted of gas gun launched flyer plates. He employed several measurement techniques to establish stress and velocity. His final data, converted to stress vs excess compression, appears in Figures A-1 and A-2. The solid line is simply a curve which appears to fit the higher stress data reasonably well and also takes into account an expected quartz phase transition at 150 Kb. The curve for the Hugoniot is drawn through the upper data points for the pragmatic reason that a lower curve does not seem to adequately predict stress levels occurring in impact tests.

The lowest point in Gregson's data is at 0.75 Kb. This is a fairly consistent precursor value seen in his stress vs time data. That stress level will be used to define the point at which significant cracking and void filling occurs.

The unloading curve in the figures is simply a path which allows the concrete to return to its solid density when loaded past the point where all voids are filled. It is a straight line which connects with the loading curve when the slopes of the two curves are equal. There is no data for this line beyond the probable solid density point at zero stress.

Measured values of Gruneisen's ratio for concrete vary but are typically around 0.1. This small value will be ignored and Gregson's data will be used to predict pressure for any density and internal energy values.

The yield strength of concrete increases as confining pressure is increased. The only data available at high confining pressures is static data generated by Chinn. Chinn's results are shown in Figures A-3 and A-4 along

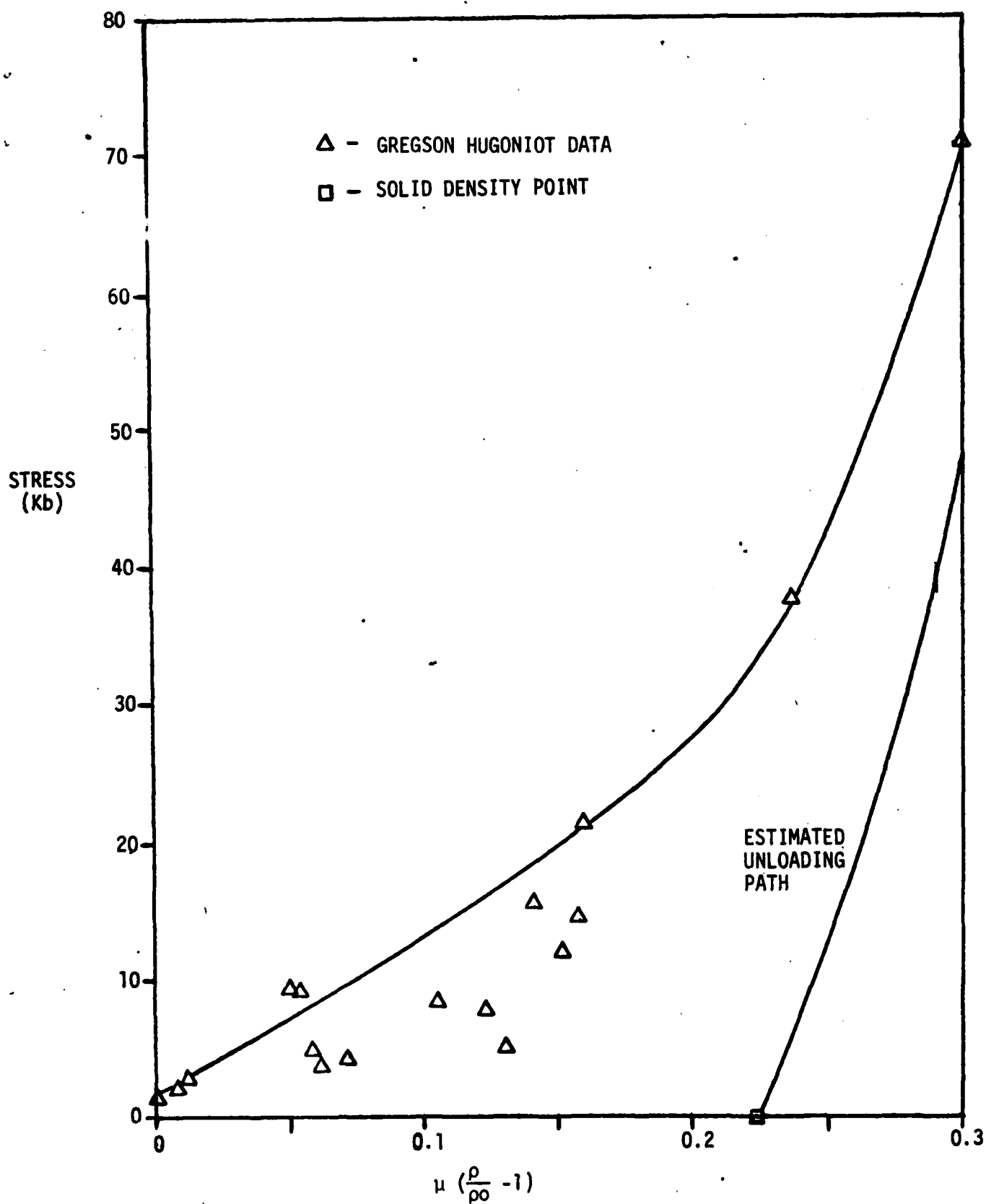


FIGURE A-1 - HUGONIOT STRESS DATA

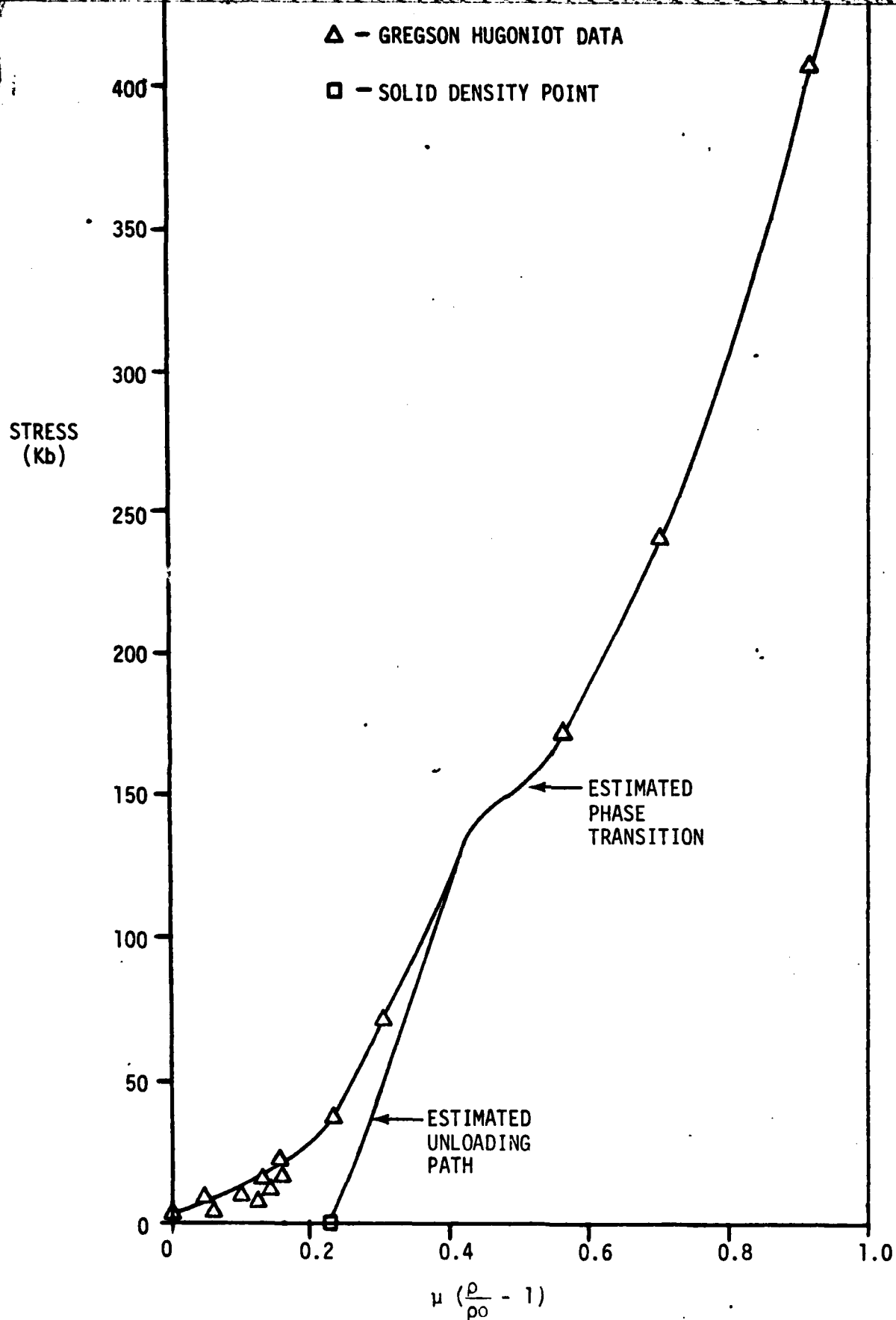


FIGURE A-2 - HUGONIOT STRESS DATA

with some typical low stress level results⁽³⁾. In the figures Y is defined as:

$$Y = [((\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_1 - \sigma_3)^2)/2]^{1/2}$$

Pressure is defined as:

$$P = -1/3 (\sigma_1 + \sigma_2 + \sigma_3)$$

where the σ_i are principle stresses at failure and are measured positive in tension. This value of pressure differs from the actual confining pressure generated hydraulically by Chinn. However, it is consistent with the way in which it is typically defined in hydrocodes. Values of Y and P are normalized in the figures by f'_c , the unconfined compressive strength of the concrete. Chinn used mixes with f'_c values varying from 3500 PSI to 10,000 PSI.

Two "theoretical" points are shown on Figure A-3. One describes failure at the unconfined compressive strength point--i.e., $Y = f'_c$ and $P = 1/3 f'_c$. The other is included because a minimum pressure criterion will be used to define tensile failure. This minimum pressure was chosen as that occurring in an unconfined tensile test assuming failure when $\sigma = 0.1 f'_c$ ⁽⁴⁾. It is numerically pleasing to have $Y = 0$ at the point where $P = -0.1 f'_c/3$. This tensile treatment is reasonable for a model not expected to be used extensively at low stress levels.

The yield strength curves of Figures A-3 and A-4 can be approximated with three straight line segments:

- (3) McHenry and Karni, "Strength of Concrete Under Combined Tensile and Compressive Stress", ACI, 54, 10, Apr 58.
- (4) Crawford, Higgins and Bultmann, "The Air Force Manual for Design and Analysis of Hardened Structures", AFWL TR 74-102, Oct 74.

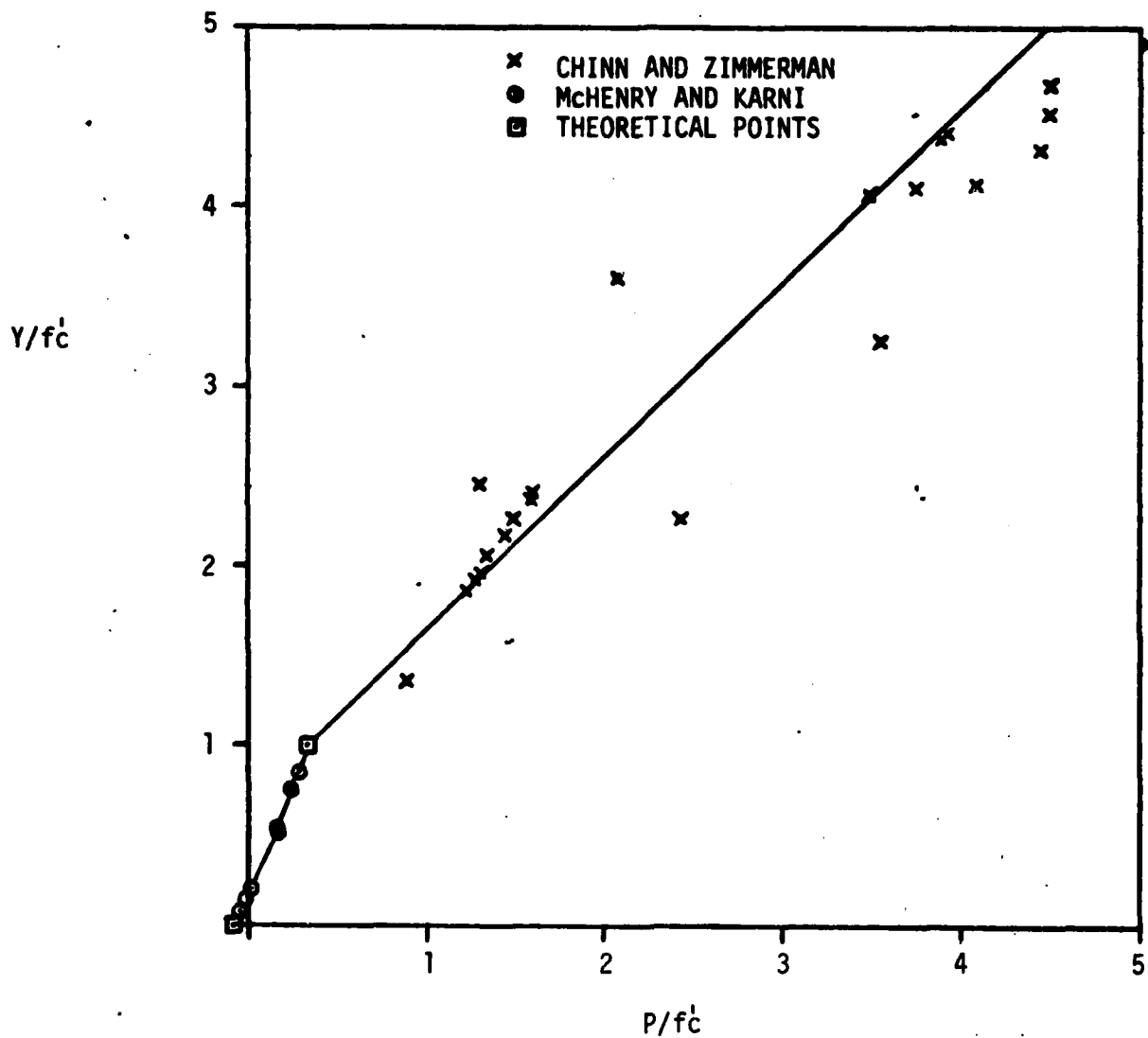


FIGURE A-3 - NORMALIZED Y vs P

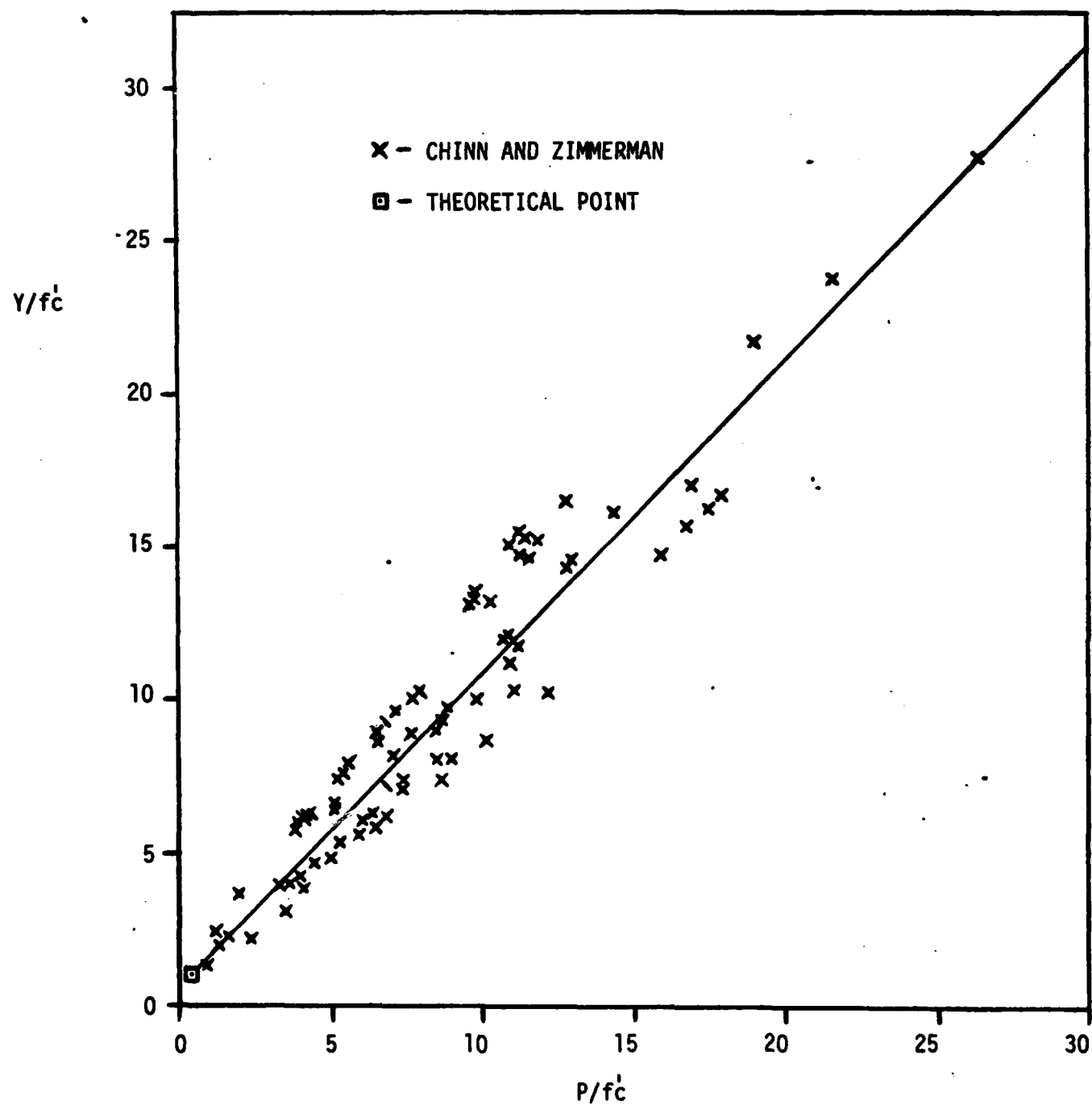


FIGURE A-4 - NORMALIZED Y vs P

$$\begin{aligned}
Y &= 0 && \text{for } P \leq -0.1 f_c' / 3 \\
Y &= 3 (P + 0.1 f_c' / 3) / 1.1 && \text{for } -0.1 f_c' / 3 < P \leq f_c' / 3 \\
Y &= P + 2/3 f_c' && \text{for } f_c' / 3 < P \leq 30 f_c' \\
Y &= 30.67 f_c' && \text{for } P > 30 f_c'
\end{aligned}$$

The limit at $P = 30 f_c'$ is not indicated in Chinn's data. It is included here because it is felt that there should be a limiting value based on similar data for soils and rocks. It is included at the level shown simply because it is known to not exist at a lower level.

It should be emphasized that the yield strength data was developed in static tests. At higher strain rates the yield strength may increase substantially. The static data is used because adequate high strain rate data is not available.

Now that Y has been determined the Hugoniot stress data generated by Gregson can be reduced to pressure data. This will be accomplished by invoking the traditional relationship

$$\sigma = P + 2/3 Y$$

which hopefully is sufficiently valid for uniaxial tests in concrete.

Letting $f_c' = 5000 \text{ PSI} = 0.345 \text{ Kilobars}$, we can use the yield strength curve to define Hugoniot pressure points. These are shown for loading in Figure A-5 by the dashed line. The difference between the stress and pressure curves builds up to a maximum of 7.05 Kb ($2/3 \times 30.67 \times f_c'$) at a pressure of 10.35 Kb. The unloading curve is left untouched--remember there is no data but the solid density point to define it anyway.

Figure A-6 is a plot of the resulting $P - \mu$ curve to 166 Kb. It should be noted that there is really no data between 63 and 166 kilobars. The

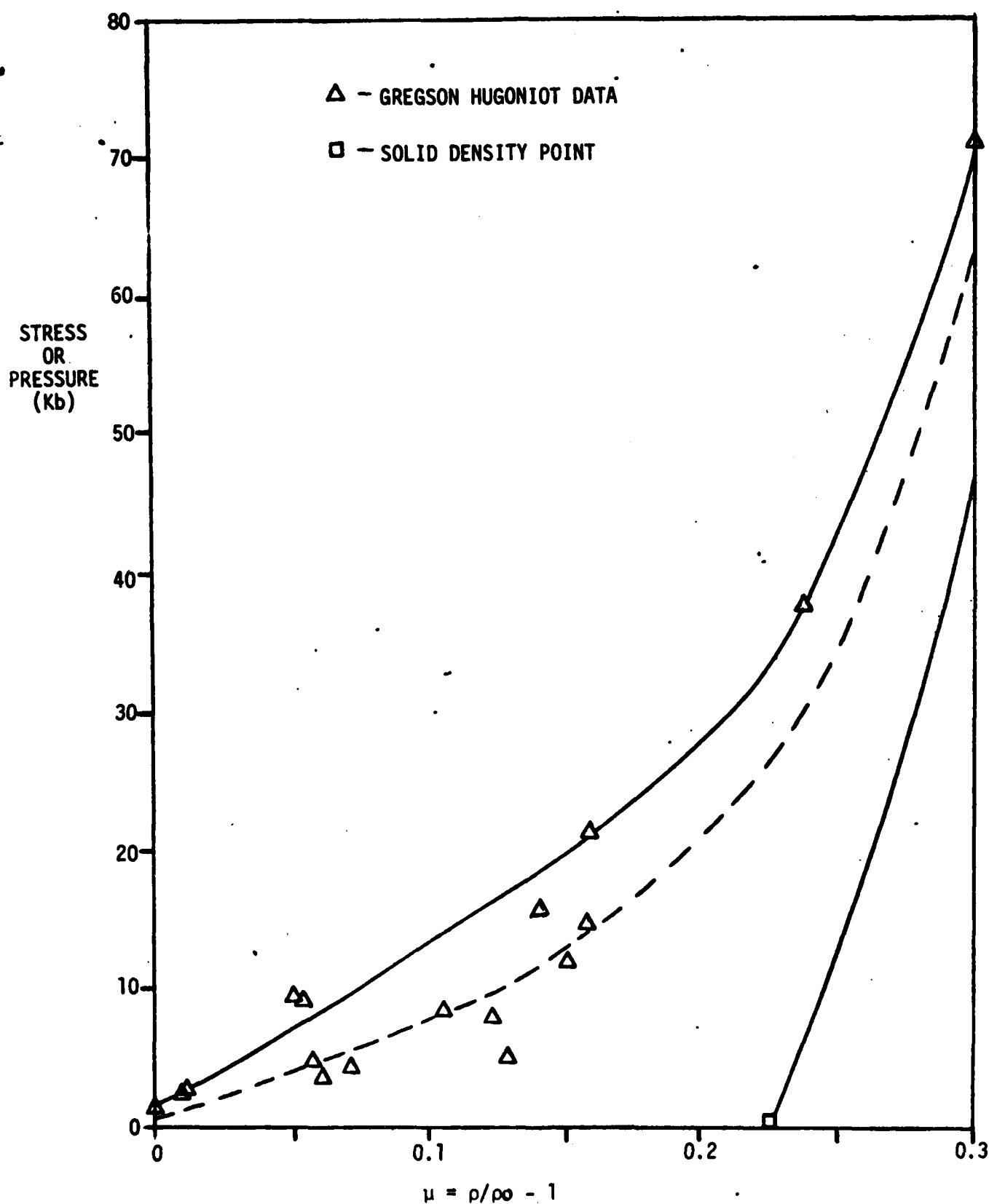
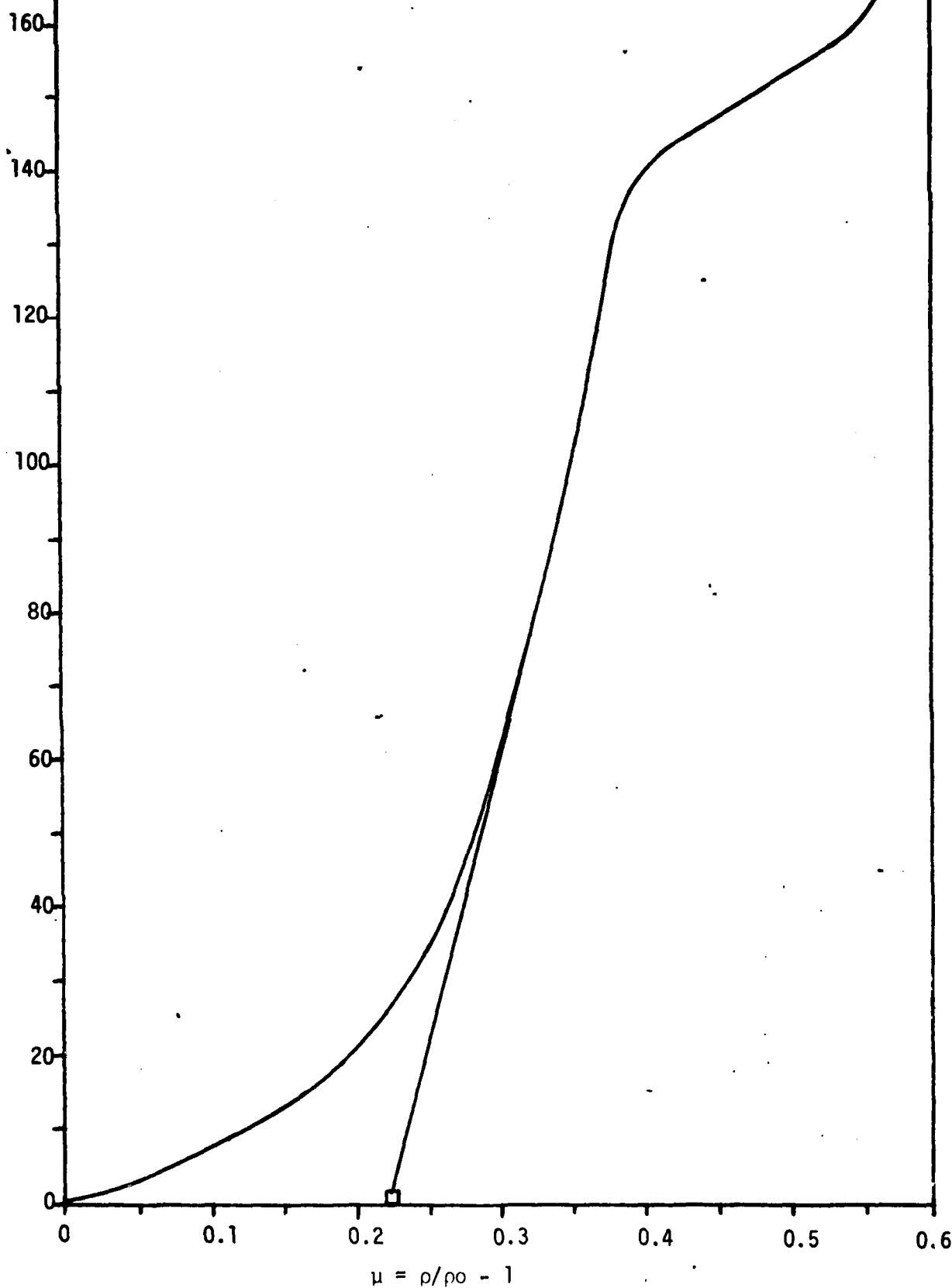


FIGURE A-5 - HUGONIOT STRESS AND PRESSURE

RESSURE
(Kb)



FIGURES A-6 - HUGONIOT PRESSURE

phase transition is consistent with data at and above the 166 kilobar level, but it may not be drawn correctly in every detail.

Below the precursor pressure of 0.358 Kb (stress level 0.75 Kb), pressure can be fitted with a straight line:

$$P = K_0 \mu$$

K_0 is determined from the Young's Modulus empirical equation⁽⁴⁾.

$$E = 33 W^{1.5} (f'_c)^{0.5} \text{ PSI } (W = \text{density in lb/ft}^3) \text{ and the relationship}$$

$$K = E/3 (1 - 2 \nu)$$

Poisson's ratio, ν , was chosen as 0.2.

Designating the value of μ at 0.358 Kb as μ_E , the loading pressure curve can be fit with the following equations:

<u>P (KB)</u>	<u>RANGE OF μ</u>
$K_0 \mu$	$-\infty$ to μ_E
$0.358 + 78.62 (\mu - \mu_E)$	μ_E to 0.1
$8 + 130 (\mu - 0.1)$	0.1 to 0.2
$21 + 420 (\mu - 0.2)$	0.2 to 0.3
$63 + 650 (\mu - 0.3)$	0.3 to 0.36607 (lockup point)
$76 + 625.5 (\mu - 0.32) + 1720.19 (\mu - 0.32)^2$	0.36607 to 0.414
$150 + 39.68 (\mu - 0.414)$	0.414 to 0.54 (transition region)
$166 + 360.5 (\mu - 0.572) + 864 (\mu - 0.572)^2$	0.54 to $+\infty$

The maximum density unloading curve is fit by

$$P = 784 (\mu - 0.223)$$

For μ_M (the largest value of μ seen by the concrete) values less than μ_E , loading, unloading and reloading take place along the same path.

For μ_M greater than the value at lockup (0.36607) loading, unloading and reloading take place along the same path. For μ_M values in between these

extremes unloading and reloading up to the loading curve take place along K_μ lines where K is chosen to vary linearly between K_0 and 784 Kilobars.

These loading curves and some unloading/reloading paths are shown in Figures A-7 and A-8.

The shear modulus G is calculated assuming that the Hooke's law relationship holds. That is,

$$G = \frac{3(1-2\nu)}{2(1+\nu)} K_b$$

where K_b is the bulk modulus, $\rho \frac{\partial p}{\partial \rho}$.

Deviators which cause the yield surface criterion to be violated are reset in the same manner as for a VonMises surface. It can be shown that the resulting plastic flow rule is inconsistent with a Mohr-Coulomb yield surface such as proposed for concrete. However, the alternative is a very complex computational model. The extra complexity cannot be justified considering the source of the yield strength model. Strain rate effects are probably far more important than a consistent flow rule.

There are many deficiencies in the model. However, it uses the available data in a reasonable manner. Any significant shortcomings in the model can be corrected only when more data is available on many types of concretes.

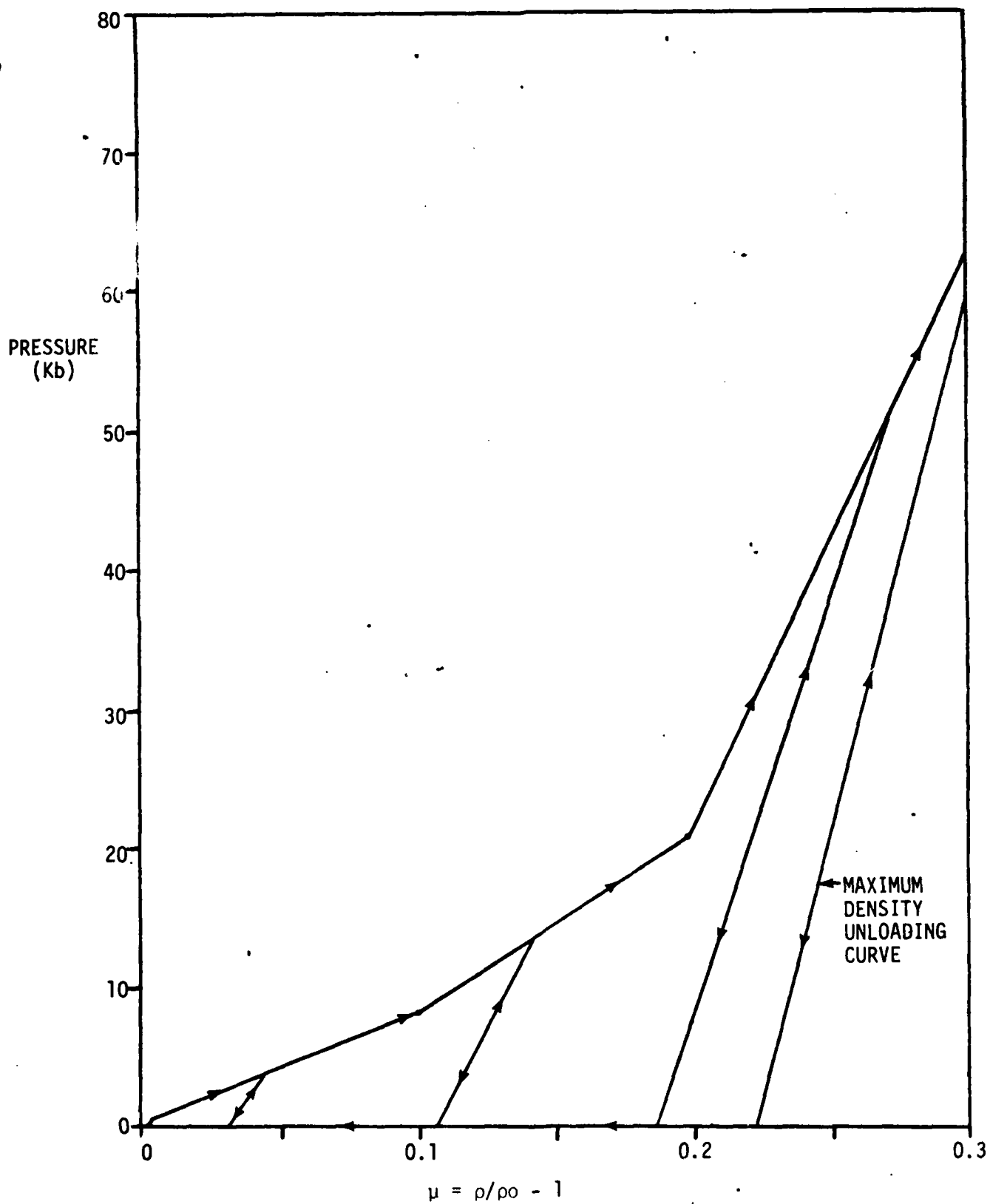
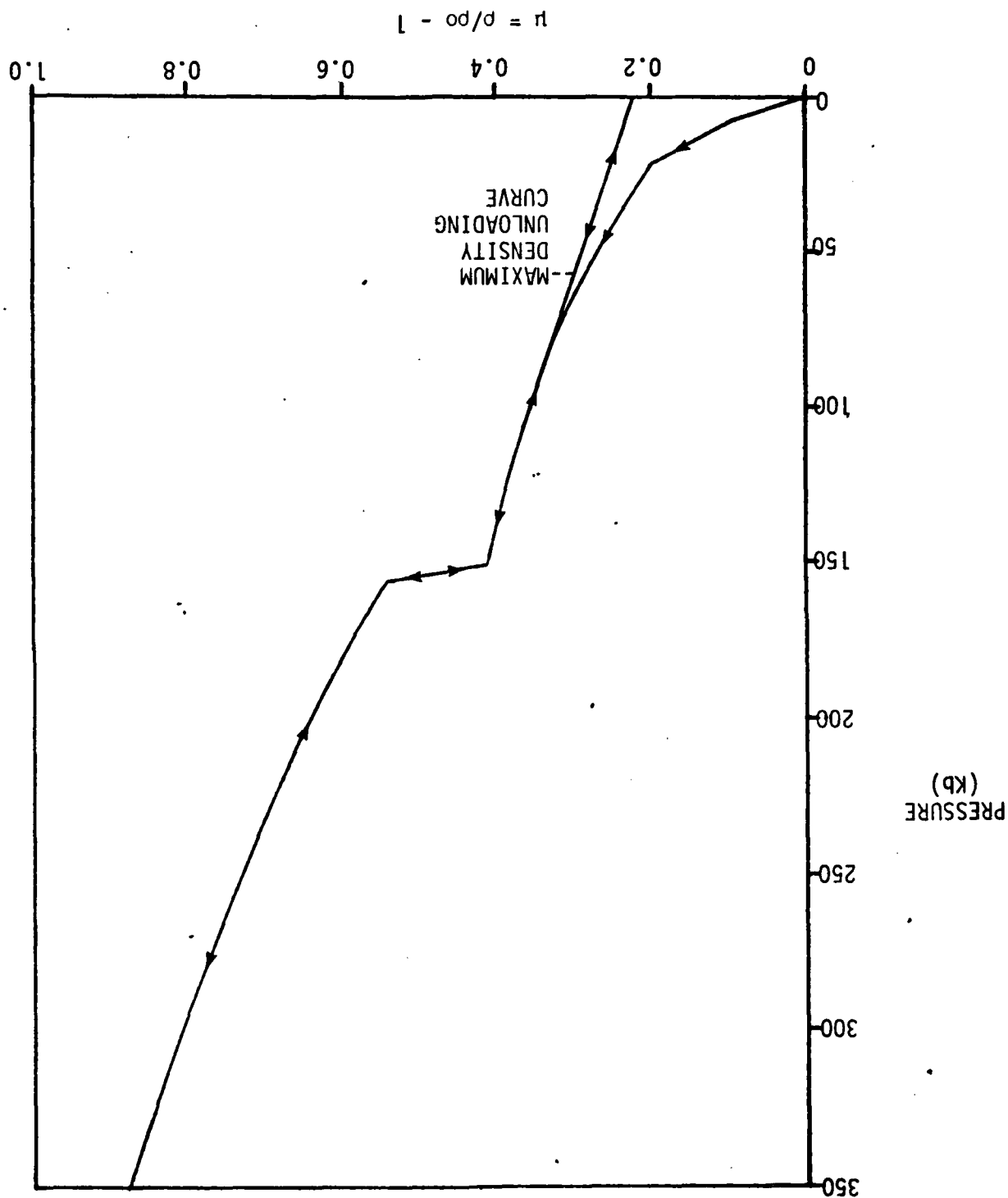


FIGURE A-7 - PRESSURE FIT

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FIGURE A-8 - PRESSURE FIT



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